# THESIS

FOR THE

## Degree of Doctor of Science of Edinburgh University,

ON THE

RELATIVE EFFICIENCY OF CERTAIN FILTERS FOR REMOVING MICRO-ORGANISMS FROM WATER, WITH SPECIAL REFERENCE TO THE NORDTMEYER-BERKEFELD AND PASTEUR-CHAMBERLAND FILTERS.



BY

SURGEON-MAJOR H. H. JOHNSTON,

ARMY MEDICAL STAFF, D.Sc., M.D., C.M., F.L.S.,

FELLOW OF THE BOTANICAL SOCIETY OF EDINBURGH, PRESIDENT OF THE SCOTTISH NATURAL HISTORY SOCIETY.

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# PREFACE.

THE experiments forming the subject of this Thesis were made in the Public Health Laboratory of Professor Sir Douglas Maclagan, in the University of Edinburgh, between October 1893 and June 1894. They were carried out at the suggestion and under the direction of Dr Hunter Stewart, to whom I am indebted for much valuable advice and universal courtesy. I am also indebted to my brother, Mr Charles S. S. Johnston, Architect, Edinburgh, for the drawings of the filters and autoclave. The experiments were made for the purpose of testing the relative efficiency of the different filters experimented with for removing micro-organisms from water, with special reference to the selection of the best filter for sterilizing drinking-water. The results of the experiments have conclusively proved that the Pasteur-Chamberland Filter (cylinders stamped "B") is undoubtedly the best and the only one on which reliance can be placed for permanently sterilizing drinking-water.

HENRY HALCRO JOHNSTON.

LEITH FORT,
SCOTLAND, *1st August* 1894.

# NOTE.

In Plate V. the filtering cylinder is shown by mistake as contained in its metal case. The Nordtmeyer-Berkefeld and Pasteur-Chamberland filtering cylinders were sterilized alone without their metal cases.

1 Litre = 1 pint 15 ounces 2 drachms 11 minims ($1\frac{3}{4}$ pint nearly).

1 cubic centimetre (1 cc.) = 16.949 minims (17 minims nearly).

# BIBLIOGRAPHY.

## MAIGNEN'S "FILTRE RAPIDE."

LAVERAN, *Des Filtres Maignen*, *Archives de Médicine Militaire*, No. 15, 1886. In this article the filter is described by Laveran.

## THE PASTEUR-CHAMBERLAND FILTER.

CHAMBERLAND, *Comptes Rendus*, Tome 99, p. 247, 1884. The filter is first described in a note by Chamberland.

MIGUEL, *Revue d'Hygiene*, p. 536, 1884, experimented with the unfiltered Seine water at $\frac{1}{3}$ atmosphere pressure, and with the water of the Ourcq at 3 to 4 atmospheres. His experiments extended over one week, and all the cultures made with the filtered water were sterile. He does not state which kind of cylinder he used.

KÜBLER, *Zeitschrift für Hygiene*, Band 8, 1890, sterilized the cylinders for 1 hour in steam at 100° C. He experimented with unfiltered Berlin water without pressure, and the results of his experiments were that the cylinders only sterilized the

filtered water for 4 days of continuous filtration. He does not mention the kind of cylinders he used, but from the rate of filtration (183 cubic centimetres per hour for each cylinder, on the first day of filtration), he appears to have used the same kind as those used in the experiments forming the subject of this Thesis, viz., those stamped "B," in which the rate of filtration is only one-third of that in the cylinders stamped "F." If he used the slow filtering cylinders stamped "B," the results of his experiments are entirely antagonistic to those obtained by the method adopted in this Thesis, in which the chances of accidental contamination of the filtered water, and the cultures made with it, were reduced to a minimum. If he used the fast filtering cylinders stamped "F," his results are also antagonistic to those obtained by Guinochet, who experimented with "F" cylinders, and came to the conclusion that the few bacterial colonies, occasionally found in some of the cultures made with filtered water, were due to accidental contamination during the process of making the cultures.

GUINOCHET, *Archives de Médicine Expérimentale*, Tome 5, p. 646, 1893, working in the Laboratory of Professor Straus, Paris, with cylinders stamped "F" for rapid filtration, at pressures of 10 to 40 mètres, for periods extending over several weeks of continuous filtration, obtained results which are very satisfactory, considering that he did not sterilize the cylinders. He came to the conclusion that the few bacterial colonies and moulds occasionally found in some of his cultures made with the filtered water, were due to accidental contamination during the process of making the cultures.

It is very important that experimenters, in publishing their results, should mention the particular kind of cylinder used, the method of preparation for experiment, and the pressure and rate of filtration of the water at the time of making the experiments; because the different results obtained by different experimenters may be due to the use of different kinds of cylinders, or to the different methods adopted of preventing accidental contamination of the cultures.

# METHOD OF PREPARING AND STERILIZING THE NUTRIENT JELLY AND APPARATUS USED IN MAKING THE CULTURES.

THE nutrient jelly was made by the well-known process of Koch. It contained 10 per cent. of gelatine, 1 per cent. of peptone, and ½ per cent. of sodium chloride. The reaction of the broth from which the jelly was prepared was, through all stages of its preparation, alkaline to litmus and turmeric paper. This was necessary on account of the amphoteric reaction of animal fluids. The test tubes, containing 10 cubic centimetres each of the nutrient gelatine jelly, were sterilized by steam at 100° C., in Hunter Stewart's autoclave (Plate V.) for one hour on three consecutive days. The plugs of cotton-wool were then scorched in a Bunsen flame, and the mouths of the test tubes covered with indiarubber caps, which had been previously sterilized by immersion in corrosive sublimate solution, 1-1000, for 2 hours, and allowed to dry between folds of filter paper. Several gross of these tubes were prepared, and in every tube the nutrient jelly remained permanently sterile. Esmarch's roll culture tubes, containing 7 cubic centimetres each of nutrient gelatine jelly, were prepared in the same manner as the test tubes.

The following glass apparatus, after having been well washed in distilled water, was sterilized by dry heat at 160°-180° C., for 1½ hour :—Petri's capsules, collecting flasks plugged with cotton-wool, and dropping tubes plugged with cotton-wool at the upper end. The collecting flasks were 200 cc. Bohemian glass vessels, having mouths ¾ inch in diameter; and the dropping tubes were made of pieces of $\frac{5}{16}$-inch glass tubing, 11

inches long, and tapered at the lower or dropping end. Fifteen drops of water from each of these dropping tubes measured 1 cubic centimetre.

Forster's boxes were well moistened inside with corrosive sublimate solution, 1-200, the day before they were used, and at the same time three sheets of filter paper moistened with the corrosive sublimate solution were placed in each box. One sheet was placed at the bottom of the box, and the other two sheets were placed, in the experiments, above the first and second pairs of Petri's capsules respectively, to prevent the entrance of micro-organisms from the air during the period of incubation of the plate cultures. During the short time occupied in pouring the melted jelly from the test tubes into Petri's capsules, the latter were placed on a glass slab moistened with corrosive sublimate solution, 1-200.

The nutrient jelly in the test tubes and in Esmarch's tubes was melted by placing the lower ends of the tubes in a beaker containing some warm corrosive sublimate solution, 1-200. Before making the cultures, the hands were well washed in distilled water, and then in corrosive sublimate solution, 1-200, after which they were allowed to dry.

The iron tongs used for removing the cotton-wool covering the lower end of the filter-nozzles, at the beginning of each series of experiments, was sterilized by heating to redness in a Bunsen flame.

# THE ATKINS PATENT WATER FILTER.

## 6-Gallons.

*MANUFACTURERS:—*
**THE ATKINS FILTER AND ENGINEERING COMPANY, Ltd.,**
**33 Bouverie Street, London, E.C.**

*Description and Method of Preparation for Experiment.*—This filter is made of stoneware, and consists of two parts, an upper and a lower, separated from each other by a stoneware diaphragm, in the centre of which is an aperture fitted with a cork containing a metal tube. The lower portion consists of a reservoir capable of holding about 2½ gallons of filtered water, and it is provided with a metal tap near the bottom. The upper portion contains the filtering material, which consists of a block of wood charcoal, 6 inches high and 5¾ inches in diameter, and fits on to the metal tube; this block being surrounded with granulated animal charcoal. The filter has a small aperture at the back of the upper rim connected with an air passage reaching to the lower part of the filter. As it was impracticable to sterilize the lower reservoir and make cultures with the filtered water at any particular time, I employed Messrs John Ford & Co., Flint Glass Manufacturers, Edinburgh, to make a cylindrical glass vessel (Plate I.), open at the upper end, and closed at the lower end, with a flat bottom, perforated at the centre by a 1⅝-inch circular aperture. The internal dimensions are—height, 11½ inches; and diameter, 11 inches. This vessel corresponds to the upper reservoir and perforated diaphragm of the Atkins Filter, and it is supported on a wooden bench, through which a circular aperture is bored opposite the aperture in the bottom of the glass vessel. The block of wood charcoal is a cylinder, 6 inches high and 5¾ inches in diameter, and it contains a central

cylindrical cavity, 3½ inches long and 1¼ inch in diameter, which is closed at the top and open at the bottom. The lower 1¼ inch of this cavity is firmly plugged with a perforated cork containing a metal tube. The thickness of the wood charcoal, between the outer surface and internal cavity of the block, is 2¼ inches. The superficial filtering area of the external surface of the block is 160 square inches, and that of the wall of the internal cavity 10 square inches, so that, in a given time, the quantity of water filtering through 1 square inch of the wall of the internal cavity is equivalent to the quantity of water filtering through 16 square inches of the external surface of the block. The metal tube referred to has an internal diameter of $\frac{1}{12}$ inch, and has a ⅞-inch flange situated 1½ inch from the upper end and 2 inches from the lower end. The upper portion of this tube is pushed through the perforated cork in the block of wood charcoal, and the lower portion through a perforated cork, for which was substituted a perforated indiarubber stopper, and the flange on the tube is in contact with the cork above and indiarubber stopper below. In the first series of experiments the lower end of the metal tube, which projects ¾ inch beyond the indiarubber stopper, was connected to a glass nozzle by means of a piece of ⅜-inch indiarubber tube. Before sterilizing the block of wood charcoal, the lower end of the glass nozzle was covered with cotton-wool secured with cord, and a screw-clip was applied to the indiarubber tube, without compressing it. The block of wood charcoal, thus prepared, was placed in distilled water, contained in an earthenware jar covered with white paper, and boiled at 100° C. in the autoclave for 1 hour on three different occasions, viz., 23rd, 24th, and 28th November 1893. Between the first and last boilings the prepared block was left immersed in the boiled distilled water in the earthenware jar covered with sterilized paper. After the third boiling, on 28th November, the indiarubber tube was compressed by means of the screw-clip, to prevent the entrance of air through the nozzle during cooling, and the prepared block of wood charcoal, held by the right hand between several folds of sterilized paper, was quickly transferred, while hot, to the glass vessel, and the indiarubber stopper inserted

into the aperture in the bottom of the vessel. The block of wood charcoal was then surrounded with 14 lbs. of granulated animal charcoal, which, with the lid and interior of the glass vessel, had previously been well washed with distilled water, but not sterilized. On 30th November the filter was filled with Edinburgh main water, and the first series of experiments was made between that date and 8th December 1893, after which the filter was allowed to stand full of water, containing innumerable micro-organisms, until 15th May 1894, when it was prepared for the second series of experiments.

In the second series of experiments the same block of wood charcoal and granulated animal charcoal were used as in the first series. The block of wood charcoal was prepared in the same manner, except that for the glass nozzle was substituted one of gun-metal, ¼ inch in diameter, 4½ inches long, and tapered at the lower end, with a terminal bore of $\frac{1}{16}$ inch. The indiarubber tube connecting the gun-metal nozzle with the metal tube of the filter is secured at both ends with silked copper wire. The block was partly surrounded with a piece of folded calico secured with an indiarubber band, to prevent the block becoming contaminated when lifted in the hand. On 15th May 1894 the granulated animal charcoal was placed in distilled water, contained in two tin pails covered with tin lids, and boiled at 120° C. (15 lbs. steam pressure to the square inch) in the autoclave for 1 hour. The steam was then turned off, and the charcoal allowed to cool in the closed autoclave until the following day, when the prepared block of wood charcoal was boiled in the same manner at 120° C. for 1 hour and, while hot, quickly transferred to the glass vessel, the lid and interior of which had been previously well washed several times with distilled water, sterilized by boiling at 120° C. for 1 hour, in the autoclave. The indiarubber band and calico were then removed from the block of wood charcoal, after which the block was surrounded with the cool granulated animal charcoal, and the mouth of the glass vessel was covered with the lid of the Atkins Filter. The second series of experiments with *Bacillus violaceus* was made between 17th and 23rd May 1894.

# MAIGNEN'S TABLE "FILTRE RAPIDE."

3-PINTS.

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*MANUFACTURERS:—*

**MAIGNEN'S "FILTRE RAPIDE" and "ANTI-CALCAIRE" CO., Ltd.,**
**43 Commercial Street, London, E.C.**

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*Description and Method of Preparation for Experiment.*—Plate II. represents this filter as prepared for use in the experiments. The glazed porcelain filtering frame is nearly cylindrical, 3 inches high, 3 inches in diameter at the lower end, and 2½ inches at the upper end. The side of the filtering frame is perforated with 70 $\frac{5}{16}$-inch holes, which in the aggregate occupy a superficial area of 5.37 square inches. The filtering frame is inclosed in a cylindrical jacket of asbestos cloth, secured at each end with asbestos cords, which are lodged in circular grooves at each end of the filtering frame. The superficial filtering area of the asbestos cloth is 21 square inches. The top of the filtering frame is flat, entire, and uncovered with asbestos cloth. The bottom of the frame is provided at the centre with a wide obconical porcelain nozzle, 1¼ inch long, fitted into the upper end of a piece of ⅜-inch indiarubber tube, and secured to the glass vessel by means of a perforated indiarubber stopper, which is inserted into a short cylindrical aperture at the centre of the bottom of the glass vessel. This indiarubber stopper takes the place of the asbestos washer supplied with the filter. The glass vessel is supported on a wooden bench, through which a circular aperture is bored to receive the short cylindrical tube at the bottom of the vessel. The lower end of the indiarubber tube was connected to glass and gun-metal nozzles in the first and second series of experiments respectively, in exactly the same manner as described for the Atkins Filter. The lower ends

of the nozzles were covered with cotton-wool secured with cord, and a screw-clip was applied to the indiarubber tube, without compressing it. On 24th November 1893 the filtering frame, thus prepared, was sterilized by steam at 100° C. for 1 hour in the autoclave, and then quickly transferred, while hot, by means of sterilized iron tongs, to the glass vessel. A charge of powdered carbo-calcis, which had been previously boiled with a litre of distilled water in a sterilized glass flask, plugged with cotton-wool, for ½ hour in the autoclave at 120° C. (15 lbs. steam pressure to the square inch), and allowed to cool, was then allowed to filter rapidly through the asbestos cloth, on which the powdered carbo-calcis was deposited in a thin film. The filtering frame was surrounded with granular carbo-calcis, which, with the porcelain screen, glass cover, and interior of the glass vessel had previously been well washed with distilled water, but not sterilized. The indiarubber tube was then closed by means of the screw-clip.

On 30th November the filter was filled with Edinburgh main water, and the first series of experiments was made between that date and 8th December 1893, after which the filter was allowed to stand full of water, containing innumerable micro-organisms, until 15th May 1894, when it was prepared for the second series of experiments. In the second series of experiments the powdered carbo-calcis was washed off the asbestos cloth and a fresh charge used. On 16th May 1894 the prepared filtering frame, provided with a gun-metal nozzle, and the powdered and granular carbo-calcis were sterilized by boiling at 120° C. for 1 hour in the autoclave, and, while hot, they were transferred to the glass vessel, which, with its cover and the screen, had previously been well washed several times with distilled water, sterilized by boiling at 120° C. for 1 hour in the autoclave. The second series of experiments with *Bacillus violaceus* was made between 17th and 23rd May 1894.

## FIRST SERIES OF EXPERIMENTS WITH THE ATKINS PATENT WATER FILTER AND MAIGNEN'S TABLE "FILTRE RAPIDE."

### Tables I. and III.

On 30th November 1893, these two filters, after having been prepared in the manner described, were filled with Edinburgh main water, containing 160 micro-organisms in each cubic centimetre, and, by means of the screw-clips compressing the india-rubber tubes, were allowed to filter slowly through the cotton-wool covering the lower ends of the glass nozzles. On the following day, after 24 hours' continuous slow filtration, the cotton-wool was removed from the nozzles with sterilized iron tongs, and some of the filtered water was received into sterilized collecting flasks, the cotton-wool plugs and necks of the flasks having been previously scorched in a Bunsen flame. Two plate cultures were then made with the filtered water from each filter, in the following manner:—Two test tubes, containing each 10 cc. of sterilized gelatine jelly, were placed in a beaker of warm corrosive sublimate solution, 1-200, until the jelly was melted. The indiarubber caps were then removed, and the cotton-wool plugs and mouths of the test tubes scorched in a Bunsen flame. By means of a sterilized dropping tube 10 and 20 drops of the filtered water were transferred from the collecting flask to the two test tubes respectively, and after mixing the water and melted jelly together by shaking, two cultures were made in sterilized Petri's capsules, which were then placed in a sterilized Forster's box, and transferred to the incubator at 19° C.

Both filters were then allowed to filter slowly continuously until 8th December, when fresh sterilized glass nozzles were inserted into the indiarubber tubes, and plate cultures made in the same manner as in the first experiment. During the week's filtration the total quantity of water that passed through the Atkins Filter was 12 litres, and Maignen's Filter 4½ litres. In the Atkins Filter, when the filter was nearly full, the rate of filtration was 17 litres per hour, which is at the rate of 106 cc. per

hour for each square inch of the outer filtering surface of the block of wood charcoal, and 1700 cc. per hour for each square inch of the inner filtering surface of the block. In Maignen's Filter the rate of filtration, when the filter was full, was 9 litres per hour, which is at the rate of 428 cc. per hour for each square inch of filtering surface of the asbestos cloth. The rate of filtration was calculated from the time taken to fill a ½-litre flask. The extreme porosity of these filters is therefore very evident, since they filter without any pressure, except that of the column of water in the filters themselves.

In No. 1 experiment the cultures were examined at the end of 4 days' incubation, and in No. 2 experiment at the end of 3 days.

*Results.*—In all the cultures from both filters the number of colonies of micro-organisms was so enormous as to be quite uncountable, and the jelly was quickly liquefied.

*Conclusions.*—In this series of experiments the granulated animal charcoal in both filters was not sterilized, but merely washed in distilled water, and if the block of wood charcoal in the Atkins Filter, and abestos cloth covered with powdered carbo-calcis in Maignen's Filter, were properly sterilized, it is evident that these filtering materials alone, exclusive of the granulated animal charcoal, were not only useless in removing micro-organisms from the water, but that they formed a suitable nidus for the rapid growth and multiplication of micro-organisms. As the Edinburgh main water placed in the filters only contained 160 micro-organisms in each cubic centimetre, it is probable that the large numbers of micro-organisms found in the filtered water were derived from the multiplication of the micro-organisms in the pores of the unsterilized granulated animal charcoal, as well as from the micro-organisms present in the Edinburgh main water. As will be noticed in the second series of experiments, it is also doubtful whether boiling at 100° C. for 1 hour on three different occasions was sufficient to sterilize the whole thickness of the block of wood charcoal in the Atkins Filter.

## SECOND SERIES OF EXPERIMENTS WITH THE ATKINS PATENT WATER FILTER AND MAIGNEN'S TABLE "FILTRE RAPIDE."

### Tables II. and IV.

On 17th May 1894, 5 cc. of a somewhat old broth culture of *Bacillus violaceus*, made on 27th March 1894, was added to a large pailful of distilled water, which had been previously boiled at 120° C. in the autoclave for 1 hour and allowed to cool to 21° C. The water was then well stirred with a sterilized metal spoon, and a plate culture made with 1 cc. of the water in sterilized gelatine jelly, from which it was ascertained that each cubic centimetre of the water contained 12 *Bacilli violacei* and 33 other micro-organisms. Both filters, after having been prepared in the manner described, were then filled with this water, and as soon as filtration was established the cotton-wool covering the lower ends of the gun-metal nozzles was removed with sterilized iron tongs. The lower ends of the nozzles were sterilized in a Bunsen flame, and immediately after the rapid filtration of 2 litres of water from the Atkins Filter and ½ litre from Maignen's Filter, the indiarubber tubes were compressed by the screw-clips until the filtered water fell in drops from the nozzles. 1 cc. (19 drops) of the filtered water from each filter was then received direct from the nozzles into test tubes containing sterilized gelatine jelly, with which plate cultures were made in sterilized Petri's capsules and placed in a sterilized Forster's box in the incubator at 19° C. The indiarubber tubes were then still more compressed by the screw-clips until just sufficient water was allowed to flow to keep the nozzles full of water. On the following day (18th May) plate cultures were made in the same manner, immediately after the rapid filtration of 1 litre of water from the Atkins Filter and ½ litre from Maignen's Filter. Plate cultures were again made in the same manner on 23rd May. In experiments Nos. 1 and 2 the cultures were examined at the end of 4 days' incubation, and in experiment No. 3 at the end of 2 days.

*Results.*—In the case of the Atkins Filter, in experiment No. 1, in which the culture was made after the rapid filtration of 2 litres of water immediately after placing the unfiltered water in the filter, there were no *Bacilli violacei*, but there were 3150 other micro-organisms in 1 cc. of the filtered water. In this series of experiments the whole of the filtering material had been previously boiled at 120° C. for 1 hour, and as the unfiltered water only contained 33 other micro-organisms in 1 cc. at the time the experiment was made, it is evident that, during boiling, sufficient heat did not penetrate the charcoal to kill all the micro-organisms lodged in its deeper pores during and after the first series of experiments. In experiment No. 2, made at the end of 1 day, and in experiment No. 3, made at the end of 6 days, the number of colonies of *Bacillus violaceus*, and especially of other micro-organisms, was so enormous as to be quite uncountable, and the jelly quickly liquefied.

In the case of Maignen's Filter, sterilization was more easily accomplished. In experiment No. 1, made after the rapid filtration of ½ litre of water immediately after placing the unfiltered water in the filter, the plate culture contained no *Bacilli violacei* and only 4 colonies of other micro-organisms in 1 cc. of the filtered water. In experiment No. 2, made on the following day, immediately after the rapid filtration of ½ litre of water, there were 7 colonies of *Bacillus violacei* and 26 colonies of other micro-organisms in the plate culture made with 1 cc. of the filtered water. In experiment No. 3, made at the end of 6 days, the number of colonies of *Bacillus violacei* and other micro-organisms was so enormous as to be quite uncountable, and the jelly quickly liquefied.

*Conclusions.*—Although the Atkins Filter was not sterilized by boiling for 1 hour at 120° C., still the enormous numbers of *Bacilli violacei* and other micro-organisms found in the filtered water, after 1 day's filtration, conclusively proves that this filter not only allows micro-organisms to pass through its pores, but the charcoal forms a suitable nidus for the growth and multiplication of micro-organisms, which are found in much greater numbers in the filtered water than in the unfiltered.

Maignen's Filter is of some service in removing micro-organisms from water on the first and second days of filtration, but after that it forms a suitable nidus for the growth and multiplication of micro-organisms, which are found in much greater numbers in the filtered water than in the unfiltered. These filters are, therefore, useless for sterilizing water, and no reliance can be placed on them for removing pathogenic micro-organisms from drinking-water.

# THE NORDTMEYER-BERKEFELD FILTER.

*MANUFACTURERS:—*
**THE BERKEFELD FILTER COMPANY, Ltd., 121 Oxford Street, London, W.**

*Description.*—This filter (Plate III) is composed of diatomaceous earth called "Kieselguhr," and it consists of a hollow cylinder, $7\frac{1}{2}$ inches long and 1 inch in diameter, which is open at the lower end only, where it is provided with a glazed porcelain nozzle. At the junction of the cylinder with the nozzle, the latter is provided with a circular flange, $1\frac{1}{2}$ inch in diameter, on which is supported a circular indiarubber washer. The internal cavity of the cylinder is cylindrical in shape, $6\frac{7}{8}$ inches long and $\frac{3}{8}$ inch in diameter, and opens into the porcelain nozzle at its lower end. The filtering material is $\frac{5}{16}$ inch thick between the outer surface and internal cavity of the cylinder. The superficial filtering area of the outer surface of the cylinder is 24.34 square inches, and that of the wall of the internal cavity 8.1 square inches, so that the quantity of water filtering through 1 square inch of the wall of the internal cavity is equivalent to the quantity of water filtering through 3 square inches of the outer surface of the cylinder. The cylinder is enclosed in a metal case, and is retained in position by means of a metal cap, which is screwed on to the lower end of the case and provided at its centre with a circular aperture, through which projects the nozzle of the cylinder. The upper end of the metal case is provided with a stop-cock, which, when the filter is in use, is screwed on to a water supply-pipe, from which the water enters the metal case, filters through the cylinder into its internal cavity, and escapes through the nozzle at the lower end of the cylinder.

# THE PASTEUR-CHAMBERLAND FILTER.

*MANUFACTURERS:—*

**THE PASTEUR-CHAMBERLAND FILTER COMPANY, 58 Rue Notre-Dame-de-Lorette, Paris.**

*AGENTS:—*

**Messrs J. DEFRIES & SONS, 147 Houndsditch, London, E.C.**

*Description.*—This filter (Plate IV.) is composed of very fine grained unglazed porcelain, and it is constructed and used in the same manner as the Nordtmeyer-Berkefeld Filter. The cylinder stamped "B" is 8 inches long and 1 inch in diameter. The internal cavity is $7\frac{7}{8}$ inches long and $\frac{10}{12}$ inch in diameter. The filtering material is $\frac{1}{12}$ inch thick between the outer surface and internal cavity of the cylinder. The superficial filtering area of the outer surface of the cylinder is 25.92 square inches, and that of the wall of the internal cavity 21.15 square inches, so that the quantity of water filtering through 1 square inch of the wall of the internal cavity is equivalent to the quantity of water filtering through 1.22 square inch of the outer surface of the cylinder. The two cylinders experimented with were stamped "B" on the upper end.

*Method of Preparation for Experiment.*—Both filters were prepared in exactly the same manner, and used under the same conditions in each series of experiments. The porcelain nozzle of each filter is connected to a gun-metal nozzle by means of a short piece of $\frac{3}{8}$-inch indiarubber tube, secured at each end with silked copper wire. The gun-metal nozzles are $4\frac{1}{2}$ inches long, $\frac{1}{4}$ inch in diameter, tapered at the lower end, with a terminal bore of $\frac{1}{16}$ inch, and, except in the first series of experiments, provided with a circular flange $\frac{7}{8}$ inch in diameter, 1 inch from the lower end of the nozzle; 19 drops from each of these gun-metal

nozzles measured 1 cubic centimetre respectively. Before sterilizing the cylinders, the indiarubber washers were placed on them, and the lower ends of the gun-metal nozzles were covered with cotton-wool secured with cord, to prevent the entrance of air micro-organisms during cooling of the cylinders before filtration was established. The two cylinders thus prepared were placed in distilled water in a tin trough, and sterilized by boiling in the autoclave. In the first series of experiments both prepared cylinders were boiled at 115° C. (12½ lbs. steam pressure to the square inch), for ¼ hour; in the second series of experiments, at 120° C. (15 lbs. steam pressure to the square inch), for ½ hour; in the third series, with the Nordtmeyer-Berkefeld Filter, at 120° C. for 1 hour; and in the last series, with both filters, at 115° C. for 1 hour. In all the series of experiments, the sterilized prepared cylinders were transferred to their metal cases while hot, and as soon as they were cool the stop-cocks were turned full on, and the water allowed to filter continuously day and night until the end of each series of experiments.

Plate IV. shows the method adopted of fixing up the filters for experiment in the laboratory. A metal water-pipe soldered to the end of a main water-tap is fixed along the top of a range of shelves for bottles. This supply-pipe is provided with (1) a gun-metal tap for supplying unfiltered water; (2) a water pressure gauge; (3) a short branch to which is fixed the Nordtmeyer-Berkefeld Filter; and (4) a terminal end to which is fixed the Pasteur-Chamberland Filter.

*Method of Making the Experiments.*—As soon as filtration was established in both filters, after having been prepared and fixed up in the manner described, the cotton-wool covering the lower ends of the gun-metal nozzles was removed with sterilized iron tongs. The gun-metal tap for unfiltered water and the gun-metal nozzles of the filters were invariably sterilized in a Bunsen flame and allowed to cool, before collecting water for making cultures with in each experiment. After sterilizing the nozzles, 10 minutes' filtration was allowed before collecting the filtered water for making cultures with, so as to ensure the

escape of all water heated in the Bunsen flame during sterilization of the nozzles. Only the lower ends of the nozzles, including the flanges, were heated in the Bunsen flame, and the subsequent 10 minutes' filtration was ample for the purpose of allowing all heated water to escape from the nozzles.

In the first series of experiments and in the first ten experiments of the second series with both filters, collecting flasks and dropping tubes were used in the same manner as described for the Atkins and Maignen's Filters ; but in all the other experiments with both filters, 1 cubic centimetre (19 drops) of filtered water was received direct from the gun-metal nozzles into each tube of sterilized gelatine jelly. This method considerably lessened the chance of air micro-organisms accidentally entering the cultures, especially in the experiments made before the gun-metal nozzles were provided with flanges. The diameter of the mouths of the collecting flasks is $\frac{3}{4}$ inch, and in the case of the Pasteur-Chamberland Filter, after three day's filtration, the mouth of the collecting flask had to be left uncovered for 1 minute, until sufficient water was received to fill the dropping tube ; after a week's filtration, for 2 minutes ; after a fortnight's filtration, for 3 minutes ; and after three weeks' filtration, for 4 or 5 minutes. On referring to Table X., second series of experiments with the Pasteur-Chamberland Filter, it will be observed that out of the first 10 experiments, in which collecting flasks and dropping tubes were used, 4 of the 10 plate cultures contained in all 7 bacterial colonies, but that in the remaining 15 experiments, the 6 plate cultures and 12 of the 13 roll cultures were absolutely sterile. In the 1 exception the roll culture contained only 1 bacterial colony. In the third series of experiments (Table XI), made with the same cylinder, stamped " B," that was used in the second series, 28 roll cultures, made on 28 consecutive days of continuous filtration, were absolutely sterile. In the case of the Nordtmeyer-Berkefeld Filter, in which the rate of filtration is greater than in the Pasteur-Chamberland Filter, the mouths of the collecting flasks were not left uncovered so long as in the case of the latter filter. In every experiment with each filter, in which 10-drop and

20-drop plate cultures were made, the filtered water was allowed to fall into each test tube of sterilized gelatine jelly respectively from the same dropping tube, without filling the dropping tube a second time. If, therefore, the filtered water contained micro-organisms in any number, it is very improbable that bacterial colonies would occur in only one of the two cultures made with filtered water from the same dropping tube. On referring to Table V., first series of experiments with the Nordtmeyer-Berkefeld Filter, it will be observed that when micro-organisms once appeared in the plate cultures, they were present in considerable numbers in both the 10-drop and 20-drop cultures in each experiment, and continued to occur in large numbers in every subsequent culture; whereas, on referring to Table IX., first series of experiments with the Pasteur-Chamberland Filter, it will be observed that out of 56 plate cultures, only 7 cultures contained 1 bacterial colony each, the remaining 49 cultures being absolutely sterile; but that in no instance did the 10-drop and 20-drop cultures, made with filtered water from the same dropping tube, both contain bacterial colonies. It is, therefore, pretty certain that the few bacterial colonies found in the cultures of the first and second series of experiments with the Pasteur-Chamberland Filter, were due to air micro-organisms having accidentally fallen into the cultures during the time the cultures were being made. The plate cultures were made with sterilized gelatine jelly in the same manner as described for the Atkins and Maignen's Filters. The roll cultures were made in Esmarch's tubes, which were rotated in Houston's frame until the jelly solidified, after which the mouths of the tubes were covered with sterilized indiarubber caps.

In the first and second series of experiments with both filters, and in the third series with the Nordtmeyer-Berkefeld Filter (Tables V., VI., VII., IX., and X.), the plate and roll cultures were incubated at 19° C. In the last series of experiments with both filters (Tables VIII. and XI.), the cultures were incubated at 21° C. The plate cultures of Edinburgh main water (Table XII.), made simultaneously with the first series of experiments with both filters, were incubated at 19° C.

In counting the bacterial colonies in the plate cultures, Petri's capsules containing the cultures were placed on a black slab divided into squares, and the number of colonies in each square was counted with the aid of a lens. The actual number of colonies in each plate culture was counted, except when the number exceeded 3000, when it was estimated approximately from the number of colonies counted in part of the culture. The number of bacterial colonies in the roll cultures was counted by means of the ingenious apparatus designed by Dr J. Buchanan Young, and figured and described by him in the *Proceedings of the Royal Society of Edinburgh*, vol. xx., p. 28, 1892-93.

In Tables V. IX., and XII., the number of bacterial colonies in 1 cubic centimetre of water is calculated from the number of colonies actually present in the 10-drop and 20-drop cultures respectively, 15 drops from each of the dropping tubes used being equivalent to 1 cubic centimetre of water. In Table XII., however, the number of moulds actually present in the 10-drop and 20-drop cultures with unfiltered Edinburgh main water is recorded, instead of the calculated number in 1 cubic centimetre of the water. Each colony is held to represent one micro-organism in the water at the time of making the cultures.

The rate of filtration of each filter was calculated on the first day from the time taken to fill a $\frac{1}{2}$-litre flask, and after that from the time taken to fill a 100-cc flask. In the second series of experiments with the Nordtmeyer-Berkefeld Filter (Table VI.), the rate of filtration, immediately after turning on the water at a pressure of 21 lbs. to the square inch, was 30 litres per hour, which is at the rate of 1.233 litre per hour for each square inch of the outer filtering surface of the cylinder, and 3.703 litres per hour for each square inch of the inner filtering surface of the cylinder. At the end of 24 hours' continuous filtration, the rate of filtration at 20 lbs. pressure was only 1.333 litre per hour, which is at the rate of 0.055 litre per hour for each square inch of the outer filtering surface and 0.165 litre per hour for each square inch of the inner filtering surface.

In the second series of experiments with the Pasteur-Chamberland Filter (Table X.), the rate of filtration, immediately

after turning on the water at a pressure of 21 lbs. to the square inch, was 6 litres per hour, which is at the rate of 0.231 litre per hour for each square inch of the outer filtering surface of the cylinder, and 0.284 litre per hour for each square inch of the inner filtering surface of the cylinder. At the end of 24 hours' continuous filtration, the rate of filtration at 20 lbs. pressure was 1.143 litre, which is at the rate of 0.044 litre per hour for each square inch of the outer filtering surface, and 0.054 litre per hour for each square inch of the inner filtering surface.

On comparing the rates of filtration through each square inch of the outer filtering surfaces of these two filters, it will be observed that, immediately after turning on the water, the rate of filtration through the Nordtmeyer-Berkefeld Filter is $5\frac{1}{3}$ times greater than that through the Pasteur-Chamberland Filter; but that at the end of 24 hours' continuous filtration, the rate of filtration is only $1\frac{1}{4}$ times greater than that through the Pasteur-Chamberland Filter.

In the first series of experiments (Tables V. and IX.), during 31 days' continuous filtration at pressures varying between 17 lbs. and 46 lbs. to the square inch, the Nordtmeyer-Berkefeld Filter maintained a slight superiority over the Pasteur-Chamberland Filter in the rate of filtration; but, after the first day's filtration, the difference between the rates of filtration through the two filters was steadily diminished. This diminution is caused by the greater deposit of sediment, in a given time, on the Nordtmeyer-Berkefeld Filter than on the Pasteur-Chamberland Filter, when both filters are used under the same conditions of pressure and continuous filtration, without cleansing the filters.

## FIRST SERIES OF EXPERIMENTS WITH THE NORDTMEYER-BERKEFELD AND PASTEUR-CHAMBERLAND FILTERS AND EDINBURGH MAIN WATER.

### Tables V., IX., and XII.

This series of experiments was commenced simultaneously with both filters on 29th January 1894. The Pasteur-Chamberland

cylinder was stamped "F," and it had a narrow flange supporting the indiarubber washer, in consequence of which the indiarubber washer was forced down over the flange by the increased water-pressure (40 lbs. to the square inch) during the first night, and on the following morning the unfiltered water was discovered escaping from the lower end of the metal case and flowing down over the indiarubber tube and gun-metal nozzle. The cylinder was removed from the metal case and another cylinder, stamped "B," with a broader flange, after having been prepared and sterilized in the same manner, was substituted for it. The experiments with the Pasteur-Chamberland Filter were, therefore, one day behind the corresponding experiments with the Nordtmeyer-Berkefeld Filter. In each experiment 10-drop and 20-drop cultures were made in sterilized Petri's capsules with unfiltered Edinburgh main water drawn from the nozzle for the purpose, and with filtered water from each of the two filters. The filters were never cleaned throughout the whole series of experiments. The plate cultures made with filtered water were examined and the number of bacterial colonies counted at the end of 7 days' incubation. The bacterial colonies in the plate cultures made with unfiltered Edinburgh main water were counted at the end of 7 days' incubation, except when the cultures showed signs of liquefying before the expiration of that time.

*Results.*—In the case of the Nordtmeyer-Berkefeld Filter (Table V.), although micro-organisms were constantly present in considerable numbers in the unfiltered water, all the plate cultures made daily with the filtered water during the first 10 days' continuous filtration were absolutely sterile; but in the eleventh day's culture there were 590 micro-organisms per cubic centimetre of filtered water in the 10-drop culture, and 770 in the 20-drop culture. In the next 4 days' cultures the numbers varied between 101 and 941. After the fifteenth experiment the filter was allowed to filter continuously day and night for 16 days longer, after which the last experiment was made on 1st March. In this experiment the 10-drop culture contained 147 micro-organisms per cubic centimetre of filtered water, and the 20-drop culture 165. The number of micro-organisms in the

plate cultures made with filtered water do not bear any relation to that in the plate cultures made simultaneously with unfiltered water. When micro-organisms first appeared in the plate cultures made with filtered water on the eleventh day of continuous filtration, there had accumulated 11 days' deposit of micro-organisms on the outer surface of the filter from the water which had passed through the filter in that period. It is not, therefore, to be expected that there should be any relation between the numbers of micro-organisms present in the filtered and unfiltered water at any particular time; but it is most probable that the micro-organisms gradually grow through the pores of the filter from the bacterial mud deposited on the outer surface of the cylinder.

In the case of the Pasteur-Chamberland Filter (Table IX.) the 10-drop and 20-drop plate cultures were made daily during the first 14 days' continuous filtration, and then on every other day during the next 28 days' continuous filtration. Of the total 56 plate cultures made with filtered water in 28 experiments, extending over a period of 6 weeks' continuous filtration, only 7 cultures contained 1 micro-organism each, the remaining 49 cultures being absolutely sterile. The 7 cultures containing micro-organisms occurred in experiments Nos. 1, 10, 14, 17, 21, 25, and 26. On removing the filtering cylinders from their metal cases at the end of the series of experiments, both cylinders were coated on the outer surface with a copious deposit of brown slimy mud. By means of a sterilized platinum wire a little quantity of this mud was transferred to a test tube of sterilized nutrient gelatine jelly and a plate culture made. The number of micro-organisms in this culture was uncountable, and the jelly was liquefied at the end of 5 days' incubation at 19° C. Some moulds were also present in the culture.

*Conclusions.*—The Nordtmeyer-Berkefeld Filter sterilized the filtered water during the first 10 days' continuous filtration, but after that the filtered water invariably contained large numbers of micro-organisms which had grown through the pores of the filter.

In the case of the Pasteur-Chamberland Filter, it is pretty certain, for the reasons previously mentioned, that the filtered water was absolutely sterilized during 6 weeks' continuous

filtration at pressures varying between 17 lbs. and 39 lbs. to the square inch, and that the 7 plate cultures, containing 1 bacterial colony each, were accidentally contaminated during the process of making the cultures.

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## SECOND SERIES OF EXPERIMENTS WITH THE NORDTMEYER-BERKEFELD AND PASTEUR-CHAMBERLAND FILTERS AND *BACILLUS VIOLACEUS* AND EDINBURGH MAIN WATER.

### Tables VI. and X.

This series of experiments was commenced simultaneously with both filters on 9th April 1894, and extended over a period of 3 weeks' continuous filtration in the case of the Nordtmeyer-Berkefeld Filter, and 6 weeks in the case of the Pasteur-Chamberland Filter. New cylinders were used in both filters of the same pattern as those used in the first series of experiments—viz., the cylinder stamped "B" in the case of the Pasteur-Chamberland Filter. The space between the sterilized cylinder and its metal case, in each filter, was filled with water containing approximately 20,000 *Bacilli violacei* in each cubic centimetre. The metal case was then screwed on to the Edinburgh main water supply-pipe, and the stop-cock turned full on. The first 100 cubic centimetres of filtered water from each filter was received into a sterilized collecting flask, and by means of sterilized dropping tubes 10-drop and 20-drop plate cultures were made with the filtered water. In the case of the Nordtmeyer-Berkefeld Filter, 20 plate cultures were made, each with 1 cubic centimetre of filtered water. The first 19 experiments were made on the first 19 days of continuous filtration, and the last experiment at the end of 21 days' continuous filtration. Eight roll cultures were also made with 1 cubic centimetre of filtered water simultaneously with the last 8 plate cultures.

In the case of the Pasteur-Chamberland Filter, 25 experiments were made, the first 16 daily, the next 8 every other day,

and the last experiment 11 days after the previous one. One plate culture was made with 1 cubic centimetre of the filtered water in each of the first 16 experiments, and 1 roll culture was made with the same quantity of filtered water in each of the last 13 experiments.

Both filters were allowed to filter continuously day and night, without cleansing, throughout the whole series of experiments; and the cultures were made at pressures varying between 18 lbs. and 36 lbs. to the square inch; but at night the pressure was greater, usually between 40 lbs. and 46 lbs.

The water, containing *Bacilli violacei*, which was placed in the filters at the beginning of this series of experiments, was prepared in the following manner:—On 9th April 1894, to a litre of distilled water, which had been previously sterilized by boiling at 120° C. in a sterilized glass flask plugged with cotton-wool for ½ hour in the autoclave and allowed to cool, 1 cubic centimetre of a broth culture of *Bacillus violaceus*, made on 27th March 1894, was added by means of a sterilized dropping tube. The *Bacilli violacei* were then well mixed with the water by shaking the flask. 10-drop and 20-drop plate cultures, in sterilized gelatine jelly, were made with this water, and at the end of 3 days' incubation at 19° C. the mean of the two cultures was approximately 20,000 *Bacilli violacei* in each cubic centimetre of the water.

The number of micro-organisms in the Edinburgh main water was not ascertained in this series of experiments, but a reference to Table XII. will show that they are always present in considerable numbers.

In the first 8 experiments with both filters the cultures were incubated at 19° C. for 7 days before they were examined and the number of bacterial colonies counted. In all the remaining cultures, with both filters, the cultures were incubated at the same temperature, and the bacterial colonies were counted at the end of 14 days' incubation.

*Results.*—In the case of the Nordtmeyer-Berkefeld Filter no *Bacilli violacei* occurred in any of the cultures. The first 3 plate cultures were sterile, but in the remaining 17 plate cultures the

number of other species of micro-organisms in 1 cubic centimetre of the filtered water varied from 4 to 172. All the roll cultures contained other species of micro-organisms, but the number of bacterial colonies was not counted, except in the last culture, which contained 17 colonies. At the end of 3 weeks' continuous filtration, 2 plate cultures in sterilized gelatine jelly were made with some of the mud deposited on the outer surface of the cylinder, but no *Bacilli violacei* occurred in either culture at the end of 10 days' incubation at 10° C. Other species of micro-organisms, however, were present in these cultures in large numbers.

In the case of the Pasteur-Chamberland Filter, no *Bacilli violacei* occurred in any of the cultures. Of the 16 plate cultures 12 were sterile and 4 contained from 1 to 3 bacterial colonies each, but these 4 non-sterile cultures occurred in the first 10 experiments in which collecting flasks and dropping tubes were used. In the remaining 15 experiments, in which the filtered water was received direct from the gun-metal nozzles into the test tubes and Esmarch's roll culture tubes, all the plate cultures and 12 of the 13 roll cultures were sterile. The 1 non-sterile roll culture contained only 1 bacterial colony. At the end of 6 weeks' continuous filtration the cylinder was washed in a litre of distilled water by means of a soft nail-brush. A plate culture in sterlized gelatine jelly was made with $\frac{1}{15}$ cubic centimetre of the muddy water in which the cylinder had been washed, and at the end of 2 days' incubation at 19° C. the number of colonies of other species of micro-organisms was uncountable, and the jelly quickly liquefied. No *Bacilli violacei* were observed in this culture.

*Conclusions.*—No *Bacilli violacei* occurred in any of the cultures made with the filtered water from both filters; but as no colonies of this species of Bacillus occurred in the plate cultures made with the bacterial mud deposited on the outer surfaces of the cylinders of both filters, it is possible that these Bacilli may have been killed out by the hosts of other species of micro-organisms deposited on the cylinders from the Edinburgh main water, before the *Bacilli violacei* had time to grow

through the pores of the Nordtmeyer-Berkefeld Filter. It is not improbable, however, that this filter may prevent the larger species of micro-organisms from passing through its pores, while the smaller species are allowed to grow or pass through. The advantage, therefore, of using ordinary Edinburgh main water for testing the sterilizing power of filters is very apparent, because it always contains considerable numbers of different species of micro-organisms of different sizes.

With reference to the other species of micro-organisms derived from the Edinburgh main water, they occurred, in the case of the Nordtmeyer-Berkefeld Filter, in every culture made with the filtered water, after the second day of continuous filtration, in numbers varying from 4 to 172 micro-organisms in each cubic centimetre of filtered water.

In the case of the Pasteur-Chamberland Filter, it is pretty certain, for the reasons previously mentioned, that the 5 non-sterile cultures, containing from 1 to 3 bacterial colonies each, were accidentally contaminated during the process of making the cultures; and that the filtered water was absolutely sterilized during 6 weeks' continuous filtration at pressures varying between 18 lbs. and 36 lbs. to the square inch.

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## THIRD SERIES OF EXPERIMENTS WITH THE NORDTMEYER-BERKEFELD FILTER AND EDINBURGH MAIN WATER.

### Table VII.

This series of experiments was commenced on 1st May 1894, and extended over a period of 3 weeks' continuous filtration without cleansing the filter. The experiments were made simultaneously with those of the latter part of the second series with the Pasteur-Chamberland Filter. The cylinder used in the second series of experiments was also used in the third series. 14 experiments were made, the first 13 daily, and the last experiment eight days after the previous one. One plate culture was

made with 1 cubic centimetre of the filtered water in each experiment, and 1 roll culture was made with the same quantity of filtered water in each of the first 8 experiments. The filtered water was received direct from the gun-metal nozzles into the test tubes and Esmarch's roll culture tubes, and the chance of air micro-organisms accidentally falling into these tubes, during the time the filtered water was being received, was reduced to a minimum by means of the circular flange, $\frac{7}{8}$-inch in diameter, on the gun-metal nozzle, 1 inch from its lower or dropping end. This flange covered the mouth of the tubes, without touching them, during the time the filtered water was being received from the lower end of the nozzle, which was inside the mouth of the tubes.

The cultures were made at pressures varying from 14 lbs. to 34 lbs. to the square inch, and they were all incubated at 19° C. for 14 days before the bacterial colonies were counted.

*Results.*—In the first 3 experiments all the plate and roll cultures were sterile. In experiment No. 4, made at the end of 3 day's continuous filtration, there were 220 colonies in the plate culture and 7 colonies in the roll culture. The remaining 10 plate cultures contained from 3 to 776 colonies each, with the exception of experiment No. 11, in which the plate culture was sterile. In No. 5 experiment the roll culture was sterile, but in the remaining 3 experiments the roll cultures contained from 2 to 80 colonies in each culture.

*Conclusions.*—In this series of experiments the Nordtmeyer-Berkefeld Filter sterilized the filtered water during 2 days' continuous filtration, at pressures varying between 15 lbs. and 20 lbs. to the square inch; but in all the subsequent experiments, with one exception, there were from 3 to 776 micro-organisms in each cubic centimetre of the filtered water. These micro-organisms were undoubtedly derived from the Edinburgh main water, with which the filter was constantly supplied, and they undoubtedly passed through the pores of the filter.

## FOURTH AND THIRD SERIES OF EXPERIMENTS WITH THE NORDTMEYER-BERKEFELD AND PASTEUR-CHAMBERLAND FILTERS RESPECTIVELY, AND *MICROCOCCUS SP.* AND EDINBURGH MAIN WATER.

TABLES VIII. AND XI.

THESE two series of experiments were commenced simultaneously on 25th May 1894, and in the case of the Nordtmeyer-Berkefeld Filter extended over 10 days' continuous filtration, and in the case of the Pasteur-Chamberland Filter, over 28 days' continuous filtration, without cleansing the filters in either case. The cylinder used in the second and third series of experiments with the Nordtmeyer-Berkefeld Filter, and the cylinder used in the second series with the Pasteur-Chamberland Filter, were also used in the present series of experiments with both filters respectively.

On 25th May 1894 the space between the sterilized cylinder and its metal case, in each filter, was filled with a diluted broth culture containing approximatety 47,250 *Micrococci sp.* in each cubic centimetre. The metal case was then screwed on to the Edinburgh main water supply-pipe, and the stop-cock turned full on. After 50 cubic centimetres of water had passed through the filter, the stop-cock was screwed down until the filtered water fell in drops from the gun-metal nozzles. In the case of the Nordtmeyer-Berkefeld Filter, 1 plate culture and 1 roll culture were then made with 1 cubic centimetre (19 drops) of filtered water received direct from the gun-metal nozzles into the test tube and Esmarch's tube respectively. In the case of the Pasteur-Chamberland Filter, 1 roll culture was made in the same manner. The stop-cocks of both filters were then turned full on, and both filters were allowed to filter continuously day and night until the end of the series of experiments.

In the case of the Nordtmeyer-Berkefeld Filter, 10 experiments were made on 10 consecutive days, at pressures varying

between 14 lbs. and 46 lbs. to the square inch; 1 plate culture was made with 1 cubic centimetre of filtered water in each experiment; and 1 roll culture was made with the same quantity of filtered water, in experiments Nos. 1 and 8.

In the case of the Pasteur-Chamberland Filter, 28 experiments were made on 28 consecutive days, at pressures varying between 12 lbs. and 46 lbs. to the square inch; 1 roll culture was made with 1 cubic centimetre of filtered water in each of the 28 experiments.

The diluted broth, containing *Micrococcus sp.*, which was placed in the filters at the beginning of the series of experiments, was prepared in the following manner:—On 19th May 1894, 100 cc. of sterilized broth were inoculated by means of a sterilized platinum wire, with part of a colony of *Micrococcus sp.*, taken from the roll culture made on 30th April 1894, in experiment No. 20 of the second series of experiments with the filtered water from the Nordtmeyer-Berkefeld Filter. After 6 days' incubation at 21° C., the 100 cc. of broth were mixed with an equal quantity of distilled water. A plate culture in sterilized gelatine jelly, made with 1 cc. of the diluted broth culture, after 7 days' incubation at 21° C., contained approximately 47,250 *Micrococci sp.* This *Micrococcus* was easily recognised by its occurring in yellow globose slow-growing non-liquefying colonies in the plate and roll cultures made with the filtered Edinburgh main water, taken from the Nordtmeyer-Berkefeld Filter. The species was not identified.

The cultures made with the filtered water from both filters were incubated at 21° C. In the case of the Nordtmeyer-Berkefeld Filter, the cultures in the first 4 experiments were incubated for 14 days, but in the remaining 6 experiments the cultures had to be examined at the end of from 2½ to 7 days, on account of the enormous numbers of micro-organisms liquefying the jelly. In the case of the Pasteur-Chamberland Filter, the cultures were examined at the end of 14 days' incubation.

*Results.*—In the case of the Nordtmeyer-Berkefeld Filter, the plate and roll cultures in the first 4 experiments were sterile, except in experiment No. 2, in which the plate culture contained

1 colony of another species of micro-organism. In this experiment the culture was probably accidentally contaminated during the process of making the culture. In experiment No. 5, made after 4 days' continuous filtration, there were 40 colonies of *Micrococcus sp.*, and 1 colony of another species of micro-organism in the plate culture. In the next experiment the plate culture contained 254 colonies of *Micrococcus sp.*, and 3 colonies of other species of micro-organisms. In the remaining 4 plate cultures and in the roll culture made in experiment No. 8, the number of colonies of *Micrococcus sp.* and other species of micro-organisms was uncountable, and the jelly was more or less liquefied.

In the case of the Pasteur-Chamberland Filter, the 28 roll cultures, made on 28 consecutive days of continuous filtration, were all absolutely sterile, notwithstanding that plate cultures made with the mud deposited on the cylinder during 27 days' continuous filtration contained enormous numbers of *Micrococci sp.*, and other species of micro-organisms.

*Conclusions.*—In this series of experiments both filters were put to a very severe test, because the diluted broth culture with which the filters were filled contained approximately 47,250 micro-organisms of *Micrococcus sp.*, which had passed through the Nordtmeyer-Berkefeld Filter in the second series of experiments with that filter. The enormous number of *Micrococci sp.*, and other species of micro-organisms in the filtered water from the Nordtmeyer-Berkefeld Filter, after the third day of continuous filtration, conclusively proves that this filter cannot permanently sterilize water, whereas the entire absence of micro-organisms from the filtered water from the Pasteur-Chamberland Filter, when subjected to precisely the same conditions, conclusively proves that the latter filter can permanently sterilize water containing micro-organisms.

## *GENERAL CONCLUSIONS.*

The Pasteur-Chamberland Filter is the best and the only one on which reliance can be placed for permanently sterilizing water. Its use is therefore recommended for sterilizing drinking-water, water used for surgical dressings, and wherever sterilized water is required for any particular purpose.

This filter is most likely to prove of valuable service in reducing the number of cases of such diseases as cholera and enteric fever in countries in which the drinking-water is contaminated with the pathogenic micro-organisms of these diseases.

These conclusions have been arrived at from the results of the three series of experiments made with the Pasteur-Chamberland cylinders stamped "B," which are intended for slow filtration. The cylinders stamped "F," for rapid filtration, were not experimented with, on account of the flange being too narrow to support the indiarubber washer when exposed to high water-pressures in the filter.

# THE ATKINS PATENT WATER FILTER.

TABLE I.—RESULTS OF THE FIRST SERIES OF EXPERIMENTS WITH EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture. | Temperature of Water ° C. | Rate of Filtration. Litres per hour. | Date of Counting Micro-organisms | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10-drop Plate Culture. | 20-drop Plate Culture. | 10-drop Plate Culture. | 20-drop Plate Culture. | Mean. | |
| 1 | 1st Dec. 1893 | Not recorded | Not recorded | 5th Dec. 1893 | Uncountable | Uncountable | 237 | 83 | 160 | Culture made after 1 day's slow filtration. |
| 2 | 8th Dec. 1893 | Not recorded | 17·000 | 11th Dec. 1893 | Uncountable | Uncountable | Not recorded | | | Culture made after the continuous slow filtration of 12 litres of water between 1st and 8th Dec. 1893. |

TABLE II.—RESULTS OF THE SECOND SERIES OF EXPERIMENTS WITH BACILLUS VIOLACEUS.

| Number of Experiment | Date of Culture. | Temperature of Water ° C. | Rate of Filtration. Litres per hour. | Date of Counting Micro-organisms | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Plate Culture. | | Plate Culture. | | |
| | | | | | Bacillus Violaceus. | Other Micro-organisms. | Bacillus Violaceus. | Other Micro-organisms. | |
| 1 | 17th May 1894 | 21·0 | 20·000 | 21st May 1894 | 0 | 3150 | 12 | 33 | Culture made after the filtration of 2 litres of water, immediately after placing the unfiltered water in the filter. |
| 2 | 18th May 1894 | 18·5 | 20·000 | 22nd May 1894 | Uncountable | Uncountable | Not recorded | | Culture made after the filtration of 1 litre of water. |
| 3 | 23rd May 1894 | 20·0 | 19·000 | 25th May 1894 | Uncountable | Uncountable | Not recorded | | Culture made after the filtration of 2 litres of water. |

# MAIGNEN'S TABLE "FILTRE RAPIDE."

TABLE III.—RESULTS OF THE FIRST SERIES OF EXPERIMENTS WITH EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture. | Temperature of Water ° C. | Rate of Filtration. Litres per hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10-drop Plate Culture. | 20-drop Plate Culture. | 10-drop Plate Culture. | 20-drop Plate Culture. | Mean. | |
| 1 | 1st Dec. 1893 | Not recorded | Not recorded | 5th Dec. 1893 | Uncountable | Uncountable | 237 | 83 | 160 | Culture made after 1 day's slow filtration. |
| 2 | 8th Dec. 1893 | Not recorded | 9·000 | 11th Dec. 1893 | Uncountable | Uncountable | Not recorded | | | Culture made after the continuous slow filtration of 4·250 litres of water between 1st and 8th Dec. 1893. |

TABLE IV.—RESULTS OF THE SECOND SERIES OF EXPERIMENTS WITH BACILLUS VIOLACEUS.

| Number of Experiment. | Date of Culture. | Temperature of Water ° C. | Rate of Filtration. Litres per hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Plate Culture. | | Plate Culture. | | |
| | | | | | Bacillus Violaceus. | Other Micro-organisms. | Bacillus Violaceus. | Other Micro-organisms. | |
| 1 | 17th May 1894 | 21·0 | 9·000 | 21st May 1894 | 0 | 4 | 12 | 33 | Culture made after the filtration of ½ litre of water, immediately after placing the unfiltered water in the filter. |
| 2 | 18th May 1894 | 18·5 | 9·000 | 22nd May 1894 | 7 | 26 | Not recorded | | Culture made after the filtration of ½ litre of water. |
| 3 | 23rd May 1894 | 20·0 | 8·200 | 25th May 1894 | Uncountable | Uncountable | Not recorded | | Culture made after the filtration of ½ litre of water. |

# THE NORDTMEYER-BERKEFELD FILTER.

TABLE V.—RESULTS OF THE FIRST SERIES OF EXPERIMENTS WITH EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 1 p.m. | Temperature of Water at 1 p.m., ° C. | Pressure of Water in Main and Rate of Filtration. | | | | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 p.m. | | Midnight. | | | | | | |
| | | | Lbs. per Square Inch. | Litres per Hour. | Lbs. per Square Inch. | Litres per Hour. | | 10-drop Plate Culture. | 20-drop Plate Culture. | | |
| .. | 29th Jan. 1894 | Not recorded | 20 | 25·714 | 40 | 2·377 | .. | .. | .. | .. | No cultures made. |
| 1 | 30th | 6·0 | 22 | 0·714 | 42 | 1·111 | 6th Feb. 1894 | 0 | 0 | 242 | |
| 2 | 31st | 4·5 | 19 | 0·454 | 40 | 0·705 | 7th | 0 | 0 | 17 | |
| 3 | 1st Feb. 1894 | 5·0 | 18 | 0·308 | 41 | 0·500 | 8th | 0 | 0 | 4 | |
| 4 | 2nd | 6·5 | 18 | 0·278 | 44 | 0·444 | 9th | 0 | 0 | 17 | |
| 5 | 3rd | 8·0 | 17 | 0·208 | 46 | 0·414 | 10th | 0 | 0 | 39 | |
| 6 | 4th | 7·5 | 29 | 0·304 | 44 | 0·400 | 11th | 0 | 0 | 15 | |
| 7 | 5th | 6·3 | 17 | 0·214 | 42 | 0·380 | 12th | 0 | 0 | 646 | |
| 8 | 6th | 7·0 | 17 | 0·193 | .. | .. | 13th | 0 | 0 | 1528 | |
| 9 | 7th | 8·0 | 18 | 0·189 | .. | .. | 14th | 0 | 0 | 158 | |
| 10 | 8th | 7·5 | 18 | 0·170 | .. | .. | 15th | 0 | 0 | 302 | |
| 11 | 9th | 7·0 | 20 | 0·176 | .. | .. | 16th | 590 | 770 | 156 | |
| 12 | 10th | 9·0 | 18 | 0·132 | .. | .. | 17th | 356 | 384 | 485 | |
| 13 | 11th | 7·3 | 25 | 0·165 | .. | .. | 18th | 131 | 101 | 316 | |
| 14 | 12th | 7·1 | 20 | 0·141 | .. | .. | 19th | 941 | 831 | 2420 | |
| 15 | 13th | 6·8 | 20 | 0·130 | .. | .. | 20th | 437 | 481 | 4372 | |
| .. | 14th | 6·9 | 22 | 0·129 | .. | .. | .. | .. | .. | .. | |
| .. | 15th | 7·7 | 22 | 0·138 | .. | .. | .. | .. | .. | 1345 | |
| .. | 16th | 6·4 | 22 | 0·133 | .. | .. | .. | .. | .. | .. | |
| .. | 17th | 7·1 | 20 | 0·114 | .. | .. | .. | .. | .. | 1124 | |
| .. | 18th | 6·0 | 31 | 0·174 | .. | .. | .. | .. | .. | .. | |
| .. | 19th | 6·8 | 21 | 0·116 | .. | .. | .. | .. | .. | 5927 | |
| .. | 20th | 6·1 | 18 | 0·101 | .. | .. | .. | .. | .. | .. | |
| .. | 21st | 5·5 | 21 | 0·108 | .. | .. | .. | .. | .. | 699 | No cultures made with the filtered water. |
| .. | 22nd | 5·8 | 22 | 0·115 | .. | .. | .. | .. | .. | .. | |
| .. | 23rd | 6·6 | 23 | 0·120 | .. | .. | .. | .. | .. | 841 | |
| .. | 24th | 6·4 | 19 | 0·090 | .. | .. | .. | .. | .. | .. | |
| .. | 25th | 6·7 | 39 | 0·150 | .. | .. | .. | .. | .. | 11,340 | |
| .. | 26th | 5·6 | 18 | 0·080 | .. | .. | .. | .. | .. | .. | |
| .. | 27th | 7·1 | 21 | 0·092 | .. | .. | .. | .. | .. | 379 | |
| .. | 28th | 6·0 | 21 | 0·088 | .. | .. | .. | .. | .. | .. | |
| 16 | 1st March 1894 | 6·5 | 23 | 0·097 | .. | .. | 8th March 1894 | 147 | 165 | 1290 | |

TABLE VI.—RESULTS OF THE SECOND SERIES OF EXPERIMENTS WITH BACILLUS VIOLACEUS AND EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 2 p.m. | Temperature of Water, ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Rate of Filtration. Litres per Hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | | | Bacilli Violacei in 1 cc. of Unfiltered Water. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plate Culture. | | Roll Culture. | | | |
| | | | | | | Bacillus Violaceus. | Other Micro-organisms. | Bacillus Violaceus. | Other Micro-organisms. | | |
| 1 | 9th April 1894 | 10·0 | 21 | 30·000 | 16th April 1894 | 0 | 0 | .. | .. | 20,000 | Culture made with 1 cc. from first 100 cc. of filtered water. |
| 2 | 10th | 10·3 | 20 | 1·333 | 17th | 0 | 0 | .. | .. | .. | |
| 3 | 11th | 10·7 | 21 | 0·923 | 18th | 0 | 0 | .. | .. | .. | |
| 4 | 12th | 11·4 | 21 | 0·727 | 19th | 0 | 4 | .. | .. | .. | |
| 5 | 13th | 10·6 | 21 | 0·585 | 20th | 0 | 4 | .. | .. | .. | |
| 6 | 14th | 10·0 | 25 | 0·616 | 21st | 0 | 10 | .. | .. | .. | |
| 7 | 15th | 8·8 | 36 | 0·666 | 22nd | 0 | 14 | .. | .. | .. | |
| 8 | 16th | 9·4 | 32 | 0·600 | 23rd | 0 | 15 | .. | .. | .. | |
| 9 | 17th | 9·8 | 21 | 0·363 | 1st May 1894 | 0 | 30 | .. | .. | .. | |
| 10 | 18th | 10·0 | 23 | 0·387 | 2nd | 0 | 51 | .. | .. | .. | |
| 11 | 19th | 10·1 | 19 | 0·308 | 3rd | 0 | 172 | .. | .. | .. | |
| 12 | 20th | 10·0 | 20 | 0·300 | 4th | 0 | 102 | .. | .. | .. | |
| 13 | 21st | 10·0 | 27 | 0·338 | 5th | 0 | 43 | 0 | Present | .. | Number of micro-organisms in roll cultures not counted. |
| 14 | 22nd | 9·6 | 35 | 0·381 | 6th | 0 | 70 | 0 | Present | .. | |
| 15 | 23rd | 10·1 | 21 | 0·246 | 7th | 0 | 12 | 0 | Present | .. | |
| 16 | 24th | 10·4 | 20 | 0·224 | 8th | 0 | 12 | 0 | Present | .. | |
| 17 | 25th | 10·0 | 21 | 0·228 | 9th | 0 | 27 | 0 | Present | .. | |
| 18 | 26th | 10·3 | 22 | 0·231 | 10th | 0 | 27 | 0 | Present | .. | |
| 19 | 27th | 10·5 | 23 | 0·238 | 11th | 0 | 9 | 0 | Present | .. | |
| .. | 28th | 9·8 | 23 | 0·235 | .. | .. | .. | .. | .. | .. | No cultures made. |
| .. | 29th | 10·3 | 36 | 0·292 | .. | .. | .. | .. | .. | .. | |
| 20 | 30th | 11·0 | 22 | 0·212 | 14th | | 19 | 0 | 17 | .. | Two *micrococci sp.* in the roll culture, from one colony of which the unfitered water, containing 47,250 *micrococci sp.* and used in the Fourth Series of Nordtmeyer-Berkefeld and Third Series of Pasteur-Chamberland Experiments, derived its micro-organisms. |

TABLE VII.—RESULTS OF THE THIRD SERIES OF EXPERIMENTS WITH EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 1 p.m. | Temperature of Water, ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Rate of Filtration. Litres per Hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Plate Culture. | Roll Culture. | |
| 1 | 1st May 1894 | 11·1 | 15 | 24·000 | 15th May 1894 | 0 | 0 | Cultures made after the filtration of 1 litre of water, immediately after placing the unfiltered water in the filter. |
| 2 | 2nd | 10·8 | 19 | 1·538 | 16th | 0 | 0 | |
| 3 | 3rd | 10·7 | 20 | 0·882 | 17th | 0 | 0 | |
| 4 | 4th | 10·1 | 19 | 0·674 | 18th | 220 | 7 | |
| 5 | 5th (mid-day) | 10·5 | 14 | 0·500 | 19th | 8 | 0 | 3 *Micrococci sp.* in plate culture. |
| 6 | 6th | 10·0 | 34 | 0·685 | 20th | 3 | 80 | |
| 7 | 7th | 11·1 | 22 | 0·468 | 21st | 22 | 2 | 1 *Micrococcus sp.* in plate culture. |
| 8 | 8th | 10·8 | 20 | 0·421 | 22nd | 8 | 4 | |
| 9 | 9th | 10·5 | 18 | 0·358 | 23rd | 352 | ... | |
| 10 | 10th | 10·6 | 20 | 0·375 | 24th | 36 | ... | |
| 11 | 11th | 11·3 | 18 | 0·338 | 25th | 0 | ... | |
| 12 | 12th | 11·7 | 18 | 0·315 | 26th | 34 | ... | |
| 13 | 13th | 10·4 | 34 | 0·444 | 27th | 776 | ... | |
| 14 | 21st | 11·7 | 22 | 0·200 | 4th June 1894 | 102 | ... | |

TABLE VIII.—RESULTS OF THE FOURTH SERIES OF EXPERIMENTS WITH MICROCOCCUS SP. AND EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 2 p.m. | Temperature of Water, ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Rate of Filtration. Litres per Hour.. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | | | Micrococci sp. in 1 cc. of Unfiltered Water. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plate Culture. | | Roll Culture. | | | |
| | | | | | | Micrococcus sp. | Other Micro-organisms. | Micrococcus sp. | Other Micro-organisms. | | |
| 1 | 25th May 1894 | 11·4 | 21 | 27·272 | 8th June 1894 | 0 | 0 | 0 | 0 | 47,250 | Culture made after the filtration of 50 cc. of water, immediately after placing the unfiltered water in the filter. |
| 2 | 26th | 11·6 | 21 | 2·182 | 9th | 0 | 1 | ... | ... | ... | |
| 3 | 27th | 10·8 | 36 | 1·463 | 10th | 0 | 0 | ... | ... | ... | |
| 4 | 28th | 11·6 | 19 | 0·760 | 11th | 0 | 0 | ... | ... | ... | |
| 5 | 29th | 10·9 | 17 | 0·631 | 5th | 40 | 1 | ... | ... | ... | |
| 6 | 30th | 10·8 | 20 | 0·540 | 6th | 254 | 3 | ... | ... | ... | |
| 7 | 31st | 11·3 | 21 | 0·472 | 5th | Uncountable | Uncountable | ... | ... | ... | All the cultures partly liquefied. |
| 8 | 1st June 1894 | 11·0 | 16 | 0·353 | 5th | Uncountable | Uncountable | Uncountable | Uncountable | ... | |
| 9 | 2nd (mid-day) | 11·7 | 14 | 0·308 | 5th | Uncountable | Uncountable | ... | ... | ... | |
| 10 | 3rd (midnight) | 11·8 | 46 | 0·600 | 6th | Uncountable | Uncountable | ... | ... | ... | |

TABLE IX.—RESULTS OF THE FIRST SERIES OF EXPERIMENTS WITH EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 1 p.m. | Temperature of Water at 1 p.m., ° C. | Pressure of Water in Main and Rate of Filtration. | | | | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Micro-organisms in 1 cc. of Unfiltered Water. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 p.m. | | Midnight. | | | 10-drop Plate Culture. | 20-drop Plate Culture. | | |
| | | | Lbs. per Square Inch. | Litres per Hour. | Lbs. per Square Inch. | Litres per Hour. | | | | | |
| .. | 30th Jan. 1894 | 6·0 | 22 | 5·000 | 42 | 2·000 | 6th Feb. 1894 | .. | .. | 242 | No culture made with the filtered water. |
| 1 | 31st | 4·5 | 19 | 0·600 | 40 | 0·800 | 7th | 0 | 1 | 17 | |
| 2 | 1st Feb. 1894 | 5·0 | 18 | 0·333 | 41 | 0·600 | 8th | 0 | 0 | 4 | |
| 3 | 2nd | 6·5 | 18 | 0·286 | 44 | 0·444 | 9th | 0 | 0 | 17 | |
| 4 | 3rd | 8·0 | 17 | 0·205 | 46 | 0·400 | 10th | 0 | 0 | 39 | |
| 5 | 4th | 7·5 | 29 | 0·285 | 44 | 0·353 | 11th | 0 | 0 | 15 | |
| 6 | 5th | 6·3 | 17 | 0·191 | 42 | 0·333 | 12th | 0 | 0 | 646 | |
| 7 | 6th | 7·0 | 17 | 0·176 | .. | .. | 13th | 0 | 0 | 1528 | |
| 8 | 7th | 8·0 | 18 | 0·176 | .. | .. | 14th | 0 | 0 | 158 | |
| 9 | 8th | 7·5 | 18 | 0·154 | .. | .. | 15th | 0 | 0 | 302 | |
| 10 | 9th | 7·0 | 20 | 0·160 | .. | .. | 16th | 1 | 0 | 156 | |
| 11 | 10th | 9·0 | 18 | 0·117 | .. | .. | 17th | 0 | 0 | 485 | |
| 12 | 11th | 7·3 | 25 | 0·149 | .. | .. | 18th | 0 | 0 | 316 | |
| 13 | 12th | 7·1 | 20 | 0·125 | .. | .. | 19th | 0 | 0 | 2420 | |
| 14 | 13th | 6·8 | 20 | 0·114 | .. | .. | 20th | 1 | 0 | 4372 | |
| .. | 14th | 6·9 | 22 | 0·110 | .. | .. | .. | .. | .. | .. | |
| 15 | 15th | 7·7 | 22 | 0·120 | .. | .. | 22nd | 0 | 0 | 1345 | |
| .. | 16th | 6·4 | 22 | 0·118 | .. | .. | .. | .. | .. | .. | |
| 16 | 17th | 7·1 | 20 | 0·103 | .. | .. | 24th | 0 | 0 | 1124 | |
| .. | 18th | 6·0 | 31 | 0·140 | .. | .. | .. | .. | .. | .. | |
| 17 | 19th | 6·8 | 21 | 0·104 | . | .. | 26th | 1 | 0 | 5927 | |
| .. | 20th | 6·1 | 18 | 0·091 | .. | .. | .. | .. | .. | .. | |
| 18 | 21st | 5·5 | 21 | 0·097 | .. | .. | 28th | 0 | 0 | 699 | |
| .. | 22nd | 5·8 | 22 | 0·103 | .. | .. | .. | .. | .. | .. | |
| 19 | 23rd | 6·6 | 23 | 0·106 | .. | .. | 2nd March 1894 | 0 | 0 | 841 | |
| .. | 24th | 6·4 | 19 | 0·080 | .. | .. | .. | .. | .. | .. | |
| 20 | 25th | 6·7 | 39 | 0·131 | .. | .. | 4th | 0 | 0 | 11,340 | |
| .. | 26th | 5·6 | 18 | 0·070 | .. | .. | .. | .. | .. | .. | |
| 21 | 27th | 7·1 | 21 | 0·082 | .. | .. | 6th | 0 | 1 | 379 | |
| .. | 28th | 6·0 | 21 | 0·079 | .. | .. | .. | .. | .. | .. | |
| 22 | 1st March 1894 | 6·5 | 23 | 0·089 | .. | . | 8th | 0 | 0 | 1290 | |
| .. | 2nd | 6·7 | 20 | 0·068 | .. | . | .. | .. | .. | .. | |
| 23 | 3rd | 7·2 | 22 | 0·082 | .. | .. | 10th | 0 | 0 | 7480 | |
| .. | 4th | 6·3 | 34 | 0·103 | .. | .. | .. | .. | .. | .. | |
| 24 | 5th | 6·2 | 23 | 0·075 | .. | . | 12th | 0 | 0 | 3591 | |
| .. | 6th | 6·4 | 20 | 0·068 | .. | .. | .. | .. | .. | .. | |
| 25 | 7th | 7·1 | 23 | 0·088 | .. | .. | 14th | 0 | 1 | 1619 | |
| .. | 8th | 6·4 | 23 | 0·084 | .. | .. | .. | .. | .. | .. | |
| 26 | 9th | 6·7 | 24 | 0·090 | .. | .. | 16th | 1 | 0 | 971 | |
| .. | 10th | 7·0 | 20 | 0·063 | .. | .. | .. | .. | .. | .. | |
| 27 | 11th | 6·2 | 38 | 0·100 | .. | .. | 18th | 0 | 0 | 159 | |
| .. | 12th | 5·8 | 20 | 0·059 | .. | .. | .. | .. | .. | .. | |
| 28 | 13th | 6·2 | 21 | 0·065 | .. | .. | 20th | 0 | 0 | 126 | |

# THE PASTEUR-CHAMBERLAND FILTER.

TABLE X.—RESULTS OF THE SECOND SERIES OF EXPERIMENTS WITH BACILLUS VIOLACEUS AND EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 2 p.m. | Temperature of Water, ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Rate of Filtration. Litres per Hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | | | Bacilli Violacei in 1 cc. of Unfiltered Water. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Plate Culture. | | Roll Culture. | | | |
| | | | | | | Bacillus Violaceus. | Other Micro-organisms. | Bacillus Violaceus. | Other Micro-organisms. | | |
| 1 | 9th April 1894 | 10·0 | 21 | 6·000 | 16th April 1894 | 0 | 0 | .. | .. | 20,000 | Culture made with 1 cc. from first 100 cc. of filtered water. |
| 2 | 10th | 10·3 | 20 | 1·143 | 17th | 0 | 0 | .. | .. | .. | |
| 3 | 11th | 10·7 | 21 | 0·846 | 18th | 0 | 0 | .. | .. | .. | |
| 4 | 12th | 11·4 | 21 | 0·666 | 19th | 0 | 2 | .. | .. | .. | |
| 5 | 13th | 10·6 | 21 | 0·534 | 20th | 0 | 3 | .. | .. | .. | Collecting flasks and dropping tubes used in making the cultures. |
| 6 | 14th | 10·0 | 25 | 0·559 | 21st | 0 | 1 | .. | .. | .. | |
| 7 | 15th | 8·8 | 36 | 0·615 | 22nd | 0 | 0 | .. | .. | .. | |
| 8 | 16th | 9·4 | 32 | 0·566 | 23rd | 0 | 0 | .. | .. | .. | |
| 9 | 17th | 9·8 | 21 | 0·342 | 1st May 1894 | 0 | 1 | .. | .. | .. | |
| 10 | 18th | 10·0 | 23 | 0·363 | 2nd | 0 | 0 | .. | .. | .. | |
| 11 | 19th | 10·1 | 19 | 0·289 | 3rd | 0 | 0 | .. | .. | .. | |
| 12 | 20th | 10·0 | 20 | 0·283 | 4th | 0 | 0 | .. | .. | .. | |
| 13 | 21st | 10·0 | 27 | 0·328 | 5th | 0 | 0 | 0 | 0 | .. | |
| 14 | 22nd | 9·6 | 35 | 0·363 | 6th | 0 | 0 | 0 | 0 | .. | |
| 15 | 23rd | 10·1 | 21 | 0·231 | 7th | 0 | 0 | 0 | 0 | .. | |
| 16 | 24th | 10·4 | 20 | 0·214 | 8th | 0 | 0 | 0 | 0 | .. | |
| .. | 25th | 10·0 | 21 | 0·216 | .. | .. | .. | .. | .. | .. | |
| 17 | 26th | 10·3 | 22 | 0·218 | 10th | .. | .. | 0 | 1 | .. | Cultures made by running 1 cc. (19 drops) of water direct into the test-tubes containing the gelatine jelly from the filter-nozzle, without the use of collecting-flasks and dropping-tubes, thereby considerably lessening the risk of air micro-organisms accidentally entering the cultures. |
| .. | 27th | 10·5 | 23 | 0·229 | .. | .. | .. | .. | .. | .. | |
| 18 | 28th | 9·8 | 23 | 0·224 | 12th | .. | .. | 0 | 0 | .. | |
| .. | 29th | 10·3 | 36 | 0·275 | .. | .. | .. | .. | .. | .. | |
| 19 | 30th | 11·0 | 22 | 0·205 | 14th | .. | .. | 0 | 0 | .. | |
| .. | 1st May 1894 | 11·1 | 18 | 0·162 | .. | .. | .. | .. | .. | .. | |
| 20 | 2nd | 10·8 | 20 | 0·165 | 16th | .. | .. | 0 | 0 | .. | |
| .. | 3rd | 10·7 | 20 | 0·155 | .. | .. | .. | .. | .. | .. | |
| 21 | 4th | 10·1 | 19 | 0·153 | 18th | .. | .. | 0 | 0 | .. | |
| .. | 5th (mid-day) | 10·5 | 13 | 0·120 | .. | .. | .. | .. | .. | .. | |
| 22 | 6th | 10·0 | 33 | 0·218 | 20th | .. | .. | 0 | 0 | .. | |
| .. | 7th | 11·1 | 22 | 0·153 | .. | .. | .. | .. | .. | .. | |
| 23 | 8th | 10·8 | 20 | 0·146 | 22nd | .. | .. | 0 | 0 | .. | |
| .. | 9th | 10·5 | 18 | 0·129 | .. | .. | .. | .. | .. | .. | |
| 24 | 10th | 10·6 | 20 | 0·144 | 24th | .. | .. | 0 | 0 | .. | |
| 25 | 21st | 11·7 | 22 | 0·113 | 4th June 1894 | .. | .. | 0 | 0 | .. | |

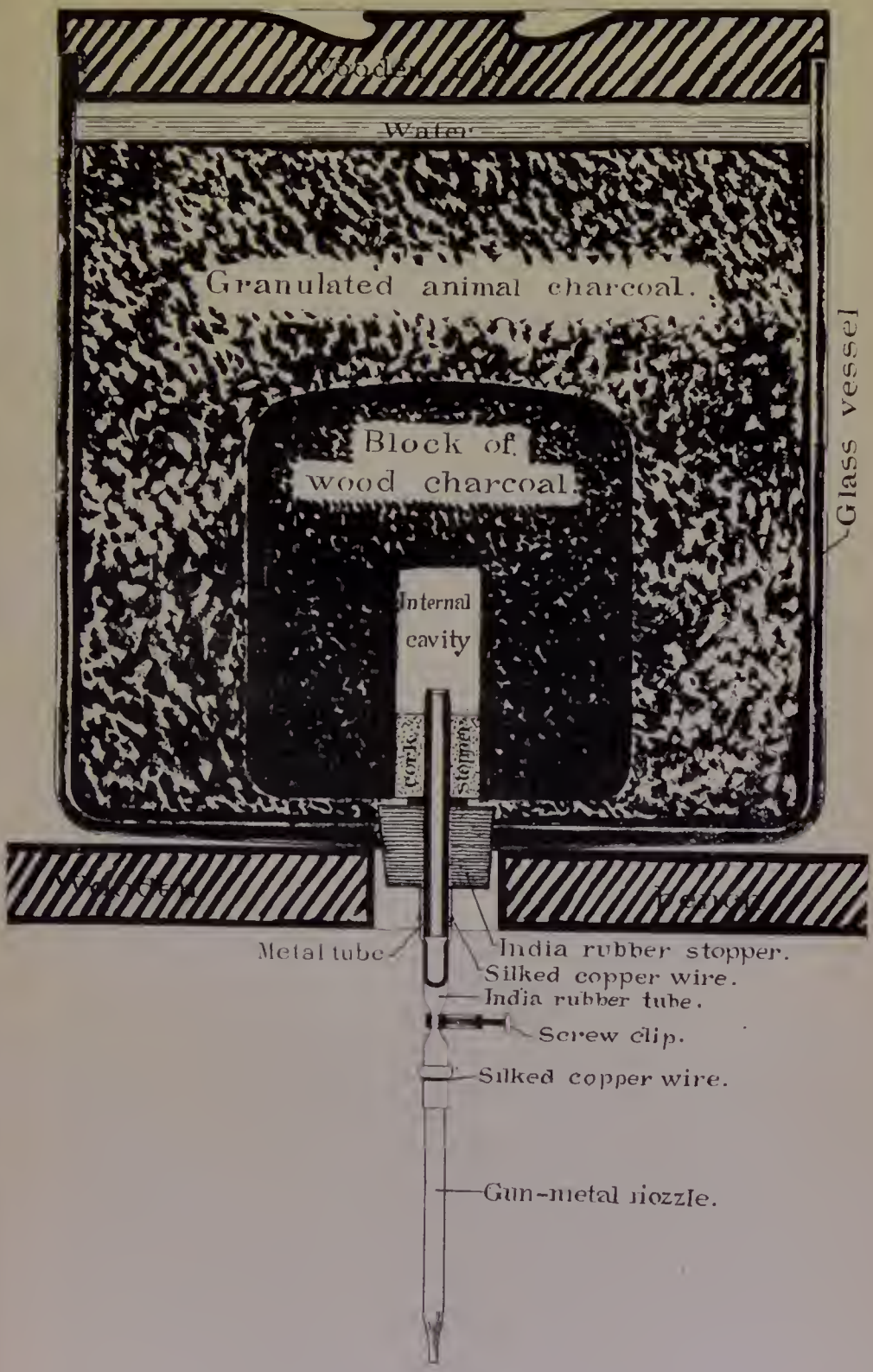
TABLE XI.—RESULTS OF THE THIRD SERIES OF EXPERIMENTS WITH MICROCOCCUS SP. AND EDINBURGH MAIN WATER.

| Number of Experiment. | Date of Culture at 2 p.m. | Temperature of Water ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Rate of Filtration. Litres per Hour. | Date of Counting Micro-organisms. | Micro-organisms in 1 cc. of Filtered Water. | | Micrococci sp. in 1 cc. of Unfiltered Water. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Roll Culture. | | | |
| | | | | | | Micrococcus sp. | Other Micro-organisms. | | |
| 1 | 25th May 1894 | 11·4 | 21 | 4·615 | 8th June 1894 | 0 | 0 | 47,250 | Culture made after the filtration of 50 cc. of water, immediately after placing the unfiltered water in the filter. |
| 2 | 26th | 11·6 | 21 | 0·909 | 9th | 0 | 0 | .. | |
| 3 | 27th | 10·8 | 36 | 0·759 | 10th | 0 | 0 | .. | |
| 4 | 28th | 11·6 | 19 | 0·438 | 11th | 0 | 0 | .. | |
| 5 | 29th | 10·9 | 17 | 0·400 | 12th | 0 | 0 | .. | |
| 6 | 30th | 10·8 | 20 | 0·361 | 13th | 0 | 0 | .. | |
| 7 | 31st | 11·3 | 21 | 0·348 | 14th | 0 | 0 | .. | |
| 8 | 1st June 1894 | 11·0 | 16 | 0·261 | 15th | 0 | 0 | .. | |
| 9 | 2nd (mid-day) | 11·7 | 14 | 0·235 | 16th | 0 | 0 | .. | |
| 10 | 3rd (midnight) | 11·8 | 46 | 0·430 | 17th | 0 | 0 | .. | |
| 11 | 4th | 11·3 | 19 | 0·240 | 18th | 0 | 0 | .. | |
| 12 | 5th | 11·3 | 21 | 0·261 | 19th | 0 | 0 | .. | |
| 13 | 6th | 11·6 | 19 | 0·235 | 20th | 0 | 0 | .. | |
| 14 | 7th | 12·8 | 20 | 0·244 | 21st | 0 | 0 | .. | |
| 15 | 8th | 11·7 | 19 | 0·222 | 22nd | 0 | 0 | .. | |
| 16 | 9th (7 p.m.) | 11·9 | 31 | 0·279 | 23rd | 0 | 0 | .. | |
| 17 | 10th (9 p.m.) | 12·0 | 42 | 0·333 | 24th | 0 | 0 | .. | |
| 18 | 11th | 11·6 | 22 | 0·210 | 25th | 0 | 0 | .. | |
| 19 | 12th | 13·3 | 19 | 0·200 | 26th | 0 | 0 | .. | |
| 20 | 13th | 15·0 | 23 | 0·218 | 27th | 0 | 0 | .. | |
| 21 | 14th | 13·8 | 23 | 0·218 | 28th | 0 | 0 | .. | |
| 22 | 15th | 13·0 | 18 | 0·179 | 29th | 0 | 0 | .. | |
| 23 | 16th (mid-day) | 14·0 | 12 | 0·132 | 30th | 0 | 0 | .. | |
| 24 | 17th (10 p.m.) | 12·4 | 41 | 0·285 | 1st July 1894 | 0 | 0 | .. | |
| 25 | 18th | 13·0 | 14 | 0·138 | 2nd | 0 | 0 | .. | |
| 26 | 19th | 12·9 | 15 | 0·143 | 3rd | 0 | 0 | .. | |
| 27 | 20th (6 pm.) | 15·5 | 22 | 0·190 | 4th | 0 | 0 | .. | |
| 28 | 21st | 15·1 | 20 | 0·182 | 5th | 0 | 0 | .. | |

TABLE XII.—MICRO-ORGANISMS IN EDINBURGH MAIN WATER.

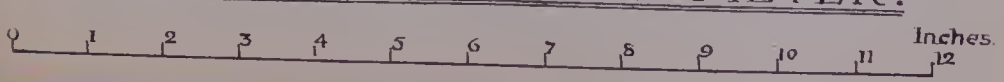
| Number of Experiment. | Corresponding Number of Experiment in First Series of Experiments. | | Date of Culture at 1 p.m. | Temperature of Water, ° C. | Pressure of Water in Main. Lbs. per Square Inch. | Date of Counting Micro-organisms. | Micro-organisms, including Moulds, in 1 cc. of Edinburgh Main Water. | | | Moulds in Edinburgh Main Water. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nordtmeyer-Berkefeld Filter. | Pasteur-Chamberland Filter. | | | | | 10-drop Plate Culture. | 20-drop Plate Culture. | Mean. | 10-drop Plate Culture. | 20-drop Plate Culture. | |
| 1 | 1 | .. | 30th Jan. 1894 | 6·0 | 22 | 4th Feb. 1894 | 209 | 275 | 242 | 0 | 0 | 20-drop culture liquefied on 5th Feb. |
| 2 | 2 | 1 | 31st | 4·5 | 19 | 7th | 19 | 15 | 17 | 0 | 0 | |
| 3 | 3 | 2 | 1st Feb. 1894 | 5·0 | 18 | 8th | 5 | 3 | 4 | 1 | 2 | |
| 4 | 4 | 3 | 2nd | 6·5 | 18 | 9th | 17 | 17 | 17 | 2 | 1 | |
| 5 | 5 | 4 | 3rd | 8·0 | 17 | 10th | 46 | 32 | 39 | 3 | 5 | 3 *Bacilli violacei* in 20-drop culture, from one colony of which were derived the *Bacilli violacei* used in the Second Series of Experiments with all the Filters. |
| 6 | 6 | 5 | 4th | 7·5 | 29 | 11th | 8 | 22 | 15 | 1 | 0 | |
| 7 | 7 | 6 | 5th | 6·3 | 17 | 12th | 662 | 630 | 646 | 0 | 0 | Both cultures liquefied on 11th Feb. |
| 8 | 8 | 7 | 6th | 7·0 | 17 | 13th | 1530 | 1526 | 1528 | 1 | 0 | |
| 9 | 9 | 8 | 7th | 8·0 | 18 | 14th | 115 | 201 | 158 | 4 | 4 | |
| 10 | 10 | 9 | 8th | 7·5 | 18 | 15th | 276 | 328 | 302 | 0 | 4 | |
| 11 | 11 | 10 | 9th | 7·0 | 20 | 16th | 134 | 178 | 156 | 1 | 2 | |
| 12 | 12 | 11 | 10th | 9·0 | 18 | 17th | 472 | 498 | 485 | 1 | 0 | |
| 13 | 13 | 12 | 11th | 7·3 | 25 | 18th | 250 | 382 | 316 | 0 | 0 | |
| 14 | 14 | 13 | 12th | 7·1 | 20 | 18th | 2420 | Liquefied | 2420 | 0 | 0 | 20-drop culture liquefied on 17th Feb. |
| 15 | 15 | 14 | 13th | 6·8 | 20 | 20th | 4224 | 4320 | 4372 | 0 | 2 | |
| 16 | .. | 15 | 15th | 7·7 | 22 | 22nd | 920 | 1770 | 1345 | 1 | 4 | |
| 17 | .. | 16 | 17th | 7·1 | 20 | 22nd | 1101 | 1147 | 1124 | 0 | 0 | Both cultures liquefied on 23rd Feb. |
| 18 | .. | 17 | 19th | 6·8 | 21 | 26th | 6885 | 4969 | 5927 | 6 | 5 | |
| 19 | .. | 18 | 21st | 5·5 | 21 | 28th | 699 | Liquefied | 699 | 14 | 0 | 20-drop culture liquefied on 25th Feb. |
| 20 | .. | 19 | 23rd | 6·6 | 23 | 2nd March 1894 | 1058 | 624 | 841 | 3 | 11 | |
| 21 | .. | 20 | 25th | 6·7 | 39 | 4th | 11,160 | 11,520 | 11,340 | 17 | 32 | 1 *Bacillus violaceus* in 20-drop culture. |
| 22 | .. | 21 | 27th | 7·1 | 21 | 6th | 349 | 409 | 379 | 4 | 5 | |
| 23 | 16 | 22 | 1st March 1894 | 6·5 | 23 | 8th | 855 | 1725 | 1290 | 10 | 24 | 1 *Bacillus violaceus* in 20-drop culture. |
| 24 | .. | 23 | 3rd | 7·2 | 22 | 10th | 7235 | 7725 | 7480 | 0 | 0 | |
| 25 | .. | 24 | 5th | 6·2 | 23 | 12th | 3780 | 3402 | 3591 | 2 | 6 | |
| 26 | .. | 25 | 7th | 7·1 | 23 | 14th | 1227 | 2011 | 1619 | 1 | 1 | |
| 27 | .. | 26 | 9th | 6·7 | 24 | 16th | 756 | 1186 | 971 | 4 | 4 | 1 *Bacillus violaceus* in 20-drop culture. |
| 28 | .. | 27 | 11th | 6·2 | 38 | 18th | 110 | 208 | 159 | 2 | 4 | |
| 29 | .. | 28 | 13th | 6·2 | 21 | 20th | 87 | 165 | 126 | 11 | 0 | 1 *Bacillus violaceus* in 20-drop culture made after running off 300 litres of water from the main. |

PLATE I.

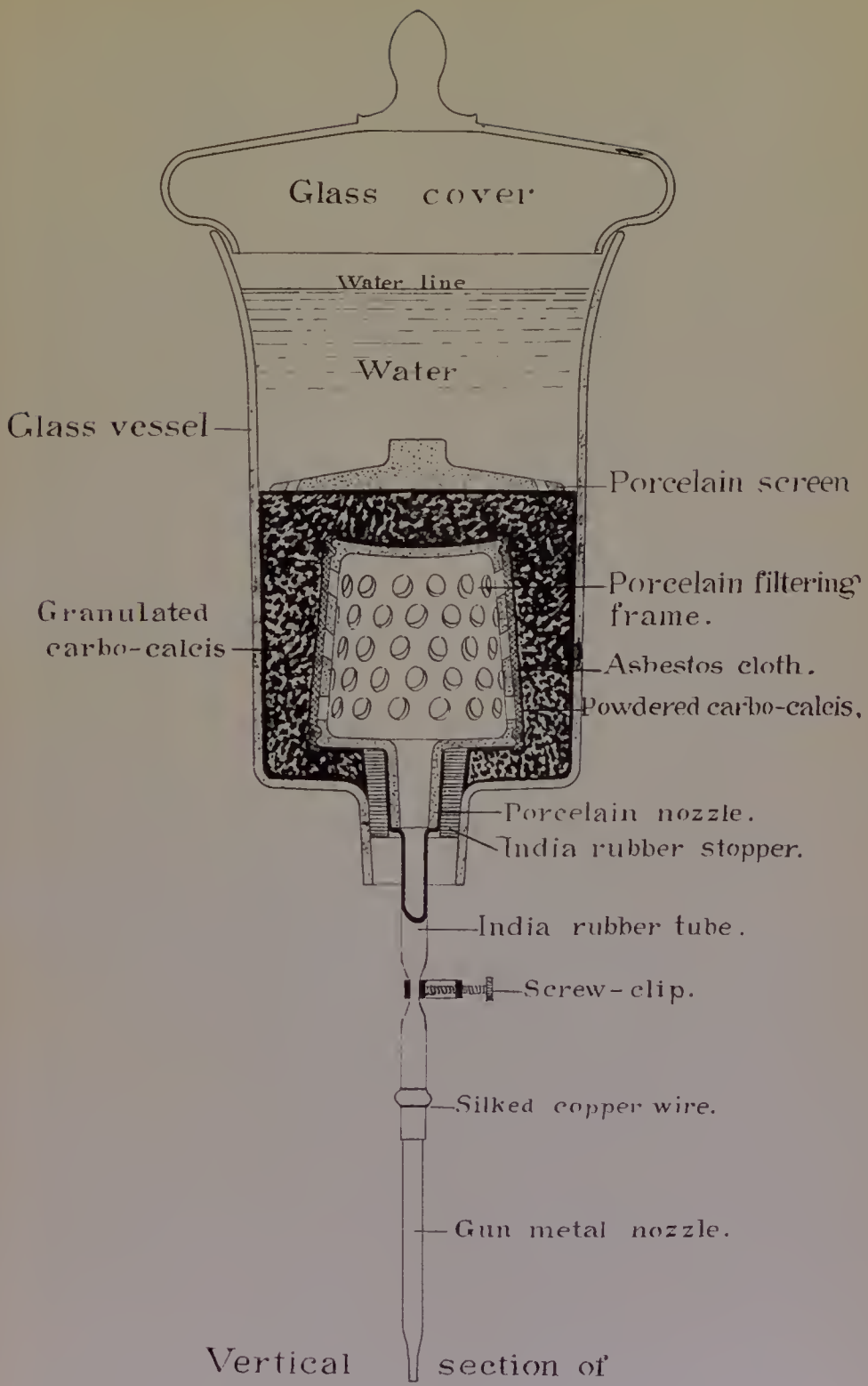



Vertical Section of the

ATKINS PATENT WATER FILTER.



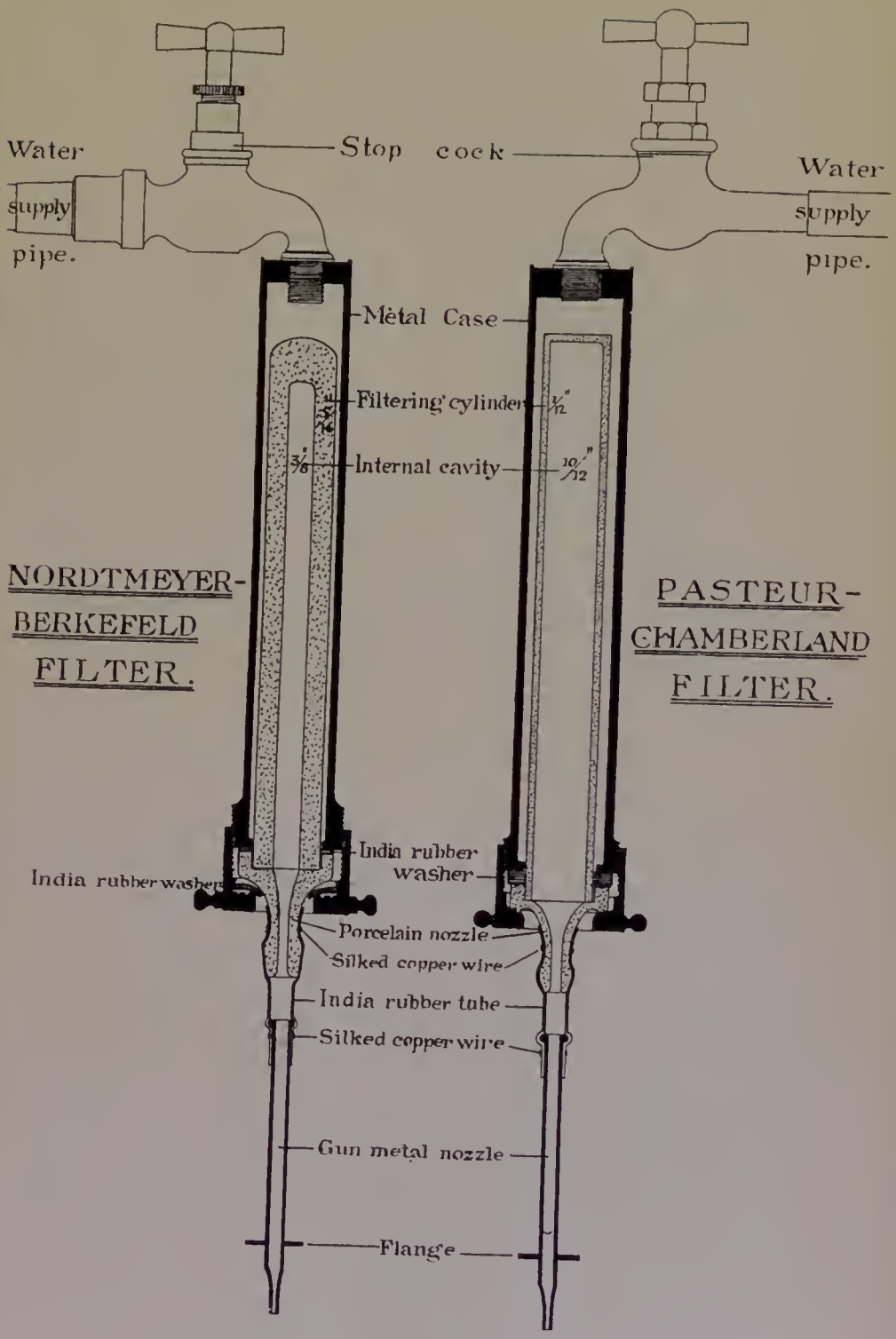
# PLATE II




Vertical section of

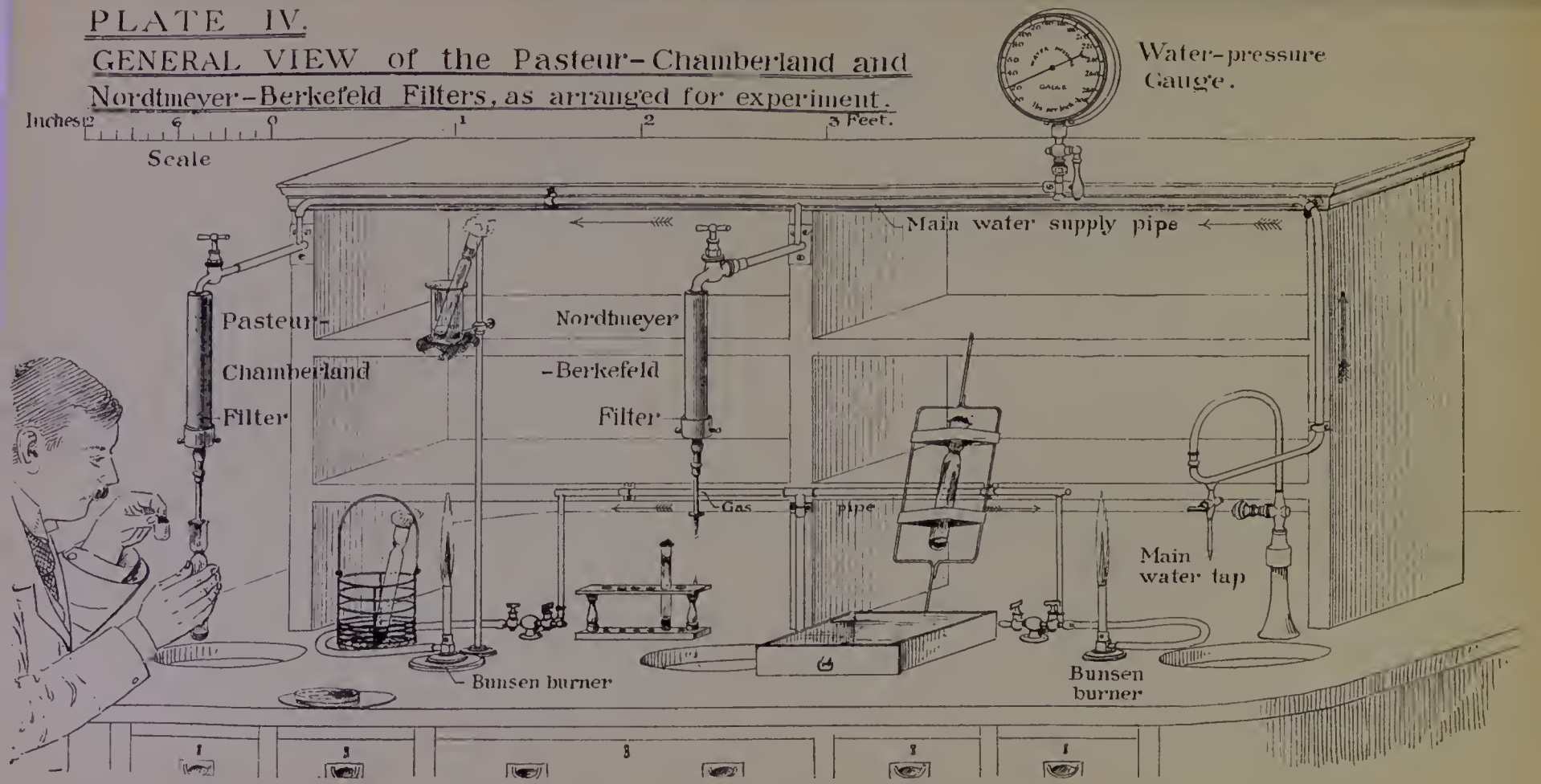
## MAIGNEN'S TABLE "FILTRE RAPIDE."

# PLATE III


Water supply pipe.
Stop cock
Water supply pipe.
Metal Case
Filtering cylinder
Internal cavity
NORDTMEYER-BERKEFELD FILTER.
PASTEUR-CHAMBERLAND FILTER.
India rubber washer
India rubber washer
Porcelain nozzle
Silked copper wire
India rubber tube
Silked copper wire
Gun metal nozzle
Flange
Vertical Sections.
0 1 2 3 4 5 6 7 8 9 10 11 12 Inches

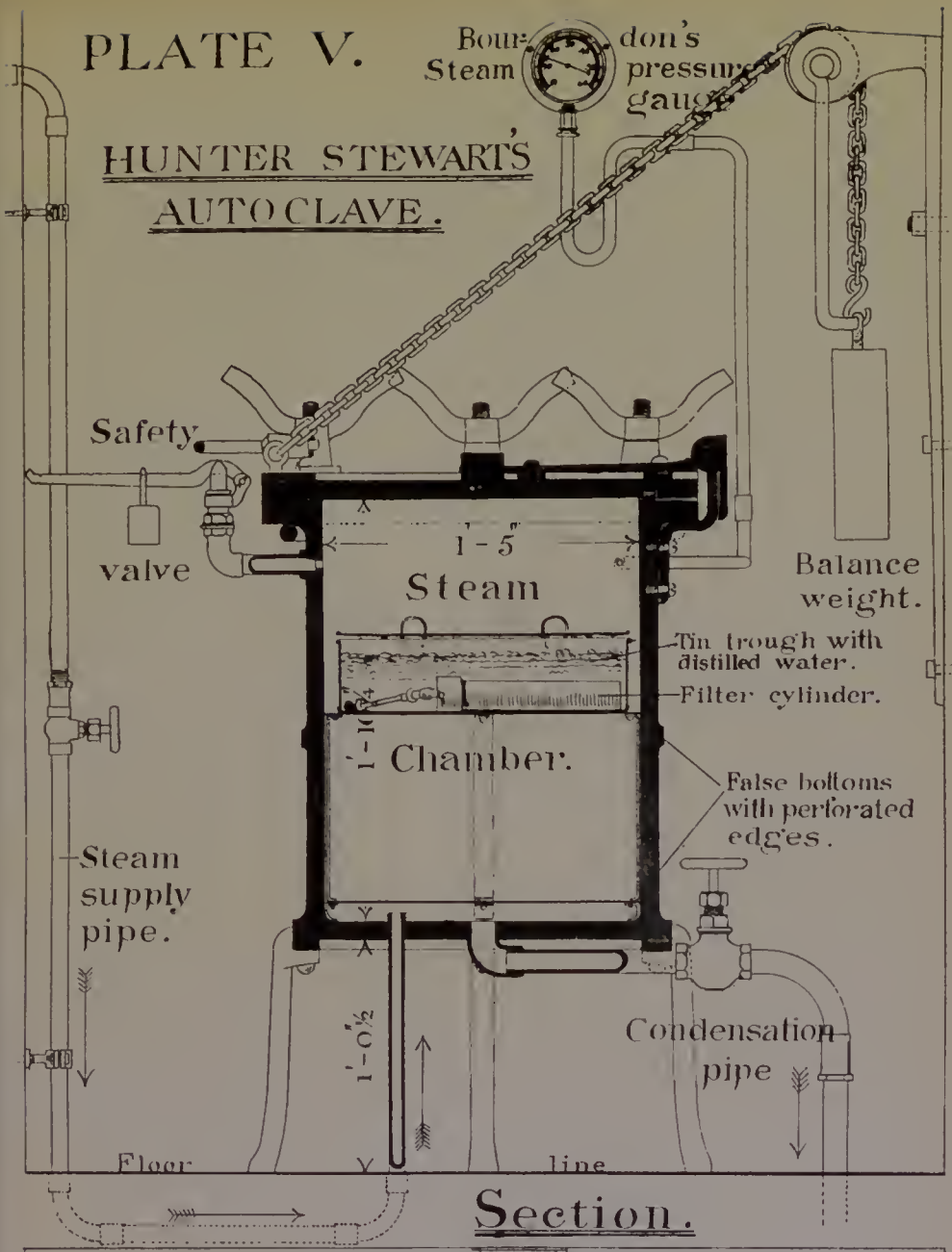
# PLATE IV.

## GENERAL VIEW of the Pasteur-Chamberland and Nordtmeyer-Berkefeld Filters, as arranged for experiment.

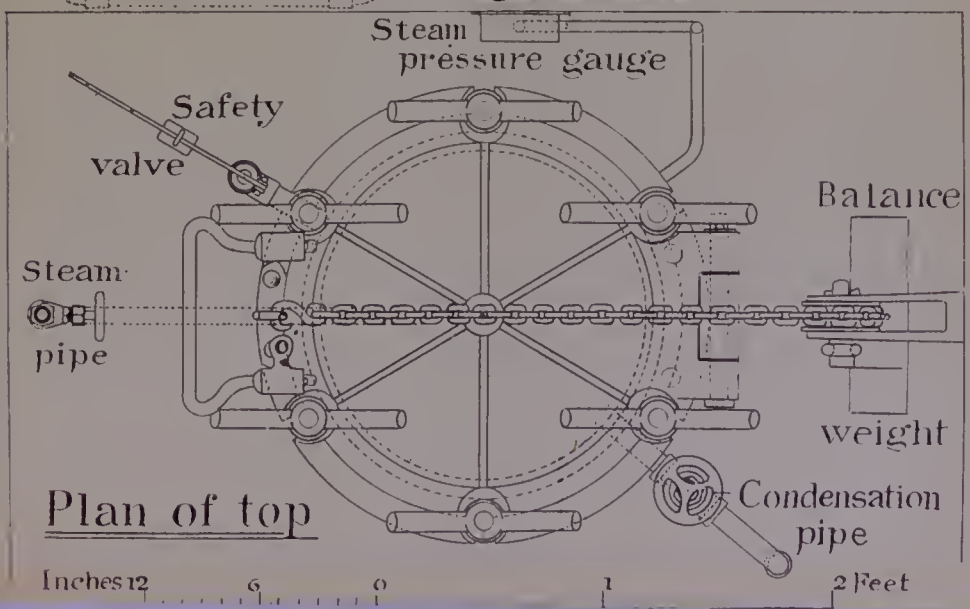


# PLATE V.

## HUNTER STEWART'S AUTOCLAVE.




Section.




Plan of top